NEAR FIELD RECEIVING WATER MONITORING OF BENTHIC COMMUNITY NEAR THE PALO ALTO WATER QUALITY CONTROL PLANT IN SOUTH SAN FRANCISCO BAY: FEBRUARY 1974 THROUGH DECEMBER 2000

U.S. GEOLOGICAL SURVEY

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CITY OF PALO ALTO, CALIFORNIA

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ABSTRACT

Analyses of the benthic community structure over a 26-year period show that changes in the community have occurred concurrent with reduced concentrations of metals in the sediment and in the tissues of the biosentinal clam *Macoma balthica* from the same area. The community has shifted from being dominated by several opportunistic species to a community where the species are more similar in abundance, a pattern that could be indicative of a more stable community that is subjected to less stress. In addition, two of the opportunistic species (*Ampelisca abdita* and *Streblospio benedicti*) that brood their young and live on the surface of the sediment in tubes have shown a continual decline in dominance coincident with the decline in metals. *Heteromastus filiformis*, a subsurface polychaete worm that lives in the sediment, consumes sediment and organic particles residing in the sediment, and reproduces by laying their eggs on or in the sediment has shown a concurrent increase in dominance. These changes in species dominance reflect a change in the community from one dominated by surface dwelling, brooding species to one with species with varying life history characteristics. Analysis of the reproductive activity of *Macoma balthica* shows increases in reproductive activity concurrent with the decline in metal concentrations in the tissue of this organism. Reproductive activity is presently stable with almost all animals reproducing during the two reproductive seasons (spring and fall) of most years.

INTRODUCTION

A common method of monitoring the effects of contaminants in aquatic systems is to examine the community structure of sediment dwelling benthic organisms (Simon 2003). Because these organisms are sedentary and are relatively long-lived, linkages between contaminant exposures and changes at the population or community level can be used to collect a time-integrated picture of ecosystem response to contaminant loading. Biomonitoring also allows us to evaluate the chronic effects of relatively low levels of contaminants as well as examine the combined effects of contaminant exposure and natural stresses in a system. Lastly, unlike many laboratory assessments of contaminant effects on organisms, field studies integrate environmental routes of exposure, including contaminants that are partitioned into the sediment, water, and diet (see Wang and Fisher 1999 for a summary of the potential transport of trace elements through food) at all life stages.

Contaminants can adversely impact benthic organisms at several organizational levels. For example, responses of a pollutant at the cellular or physiological level of an individual can result in changes at the population level, such as reductions in growth, survival and reproductive success. Community level responses to population level impairment can include changes in predator/prey interactions, competition for available resources and overall shifts in species abundance. Changes in the benthic community can ultimately result in changes at the ecosystem level due to the importance of carbon cycling in aquatic environments (see Alpine and Cloern 1992 for a local example).

Presented here is an evaluation of the benthic community changes over a 26 year period during which time the point-source metal loading from the nearby Regional Water Quality Control Plant significantly declined. Coincident with declines in metal loadings, concentrations in the sediment and in a bio-sentinel clam (*Macoma balthica*) also declined as described by the work of S.N. Luoma (U.S.G.S.; hereafter referred to as Luoma) (Hornberger et al. 2000). Concurrent, and prior to the initiation of the Luoma study, the USGS has been collecting benthic community data at three, nearby intertidal sites. Luoma's results (see Hornberger et al. 1999, 2000) have shown that sediments and local populations of clams at this location are sensitive indicators of the response of receiving waters to changes in metal output from a point-source discharger. These studies have illustrated that the reduction of metal discharge in South Bay can be reflected, within a year, by reduced near-field contamination in the both the sediment and benthic organisms of San Francisco Bay. We show here that, while the benthic community response to reduced metal output is likely to take longer, we see a response at the organismal level (i.e. reproductive activity) within a year or two and a response at the population and community levels soon thereafter. Due to the natural intra-annual variability of benthic community dynamics it is likely to take 5-10 years for a stable change in the benthic community to be expressed. Thus this study highlights the importance of long time series data that incorporates seasonal and inter-annual variability in studies of contaminant effects.

Previous monitoring of the benthic community in the near field receiving waters

Since 1974, USGS personnel have monitored and studied the benthic community and reproductive activity of *Macoma balthica* in the vicinity of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP). Our findings during the first 10 years of this study were published in Nichols and Thompson (1985a and 1985b). We found that this community was composed of non-indigenous, opportunistic species that dominated the community due to their ability to survive the many physical disturbances on the mudflat. The disturbances discussed included sediment erosion and deposition, and exposure at extreme low

tides. The possible effects of metal exposure as a disturbance factor were not considered in these analyses as the decline in metal concentrations in *Macoma balthica* and sediment had just begun.

The time series of benthic data in the present study is of particular interest because it encompasses the period when exceptionally high concentrations of copper and silver were found in the benthic animals (1970's) and the period when concentrations of the most enriched pollutants, copper and silver, declined (after 1981).

Approach

We will analyze samples at a frequency of no more than one per month. We learned in our analyses of the early (1974 through 1983) sampling (Nichols and Thompson 1985a, 1985b) that benthic samples need to be collected at a maximum time step of every other month in order to distinguish seasonal differences from inter-annual differences if the differences are small. In dynamic systems such as San Francisco Bay, distinguishing between the effects of natural seasonal changes and anthropogenic environmental stressors is more probable when samples are collected at an increased temporal intensity. The approach described here has been shown to be effective in relating changes in near field contamination to changes in benthic community structure (Kennish, 1998) and in reproductive activity of a clam (Hornberger et al. 2000), despite the complexities inherent in monitoring natural systems. By using historical data as a basis of this study, we will provide a context within which cause and effect can be assessed for change in the future.

We will look at the biological response of the benthic community to pollutant changes in the environment at three organization levels: the physiological/cellular, the population, and the community. First, we examine the tissue concentrations of metals in *Macoma balthica* during this period to determine if metal concentration changes correspond to physiological changes to the clams (i.e. reproduction). Analysis of the trace element concentration in the tissues of *Macoma balthica*, as done by Luoma, provides a measure of exposure to bioavailable pollutants and an estimate of dietary exposures to pollutants. This does not however, examine the physiological effect of the metal exposure on *Macoma balthica*. One of the more common animal responses to an environmental stressor is a change in reproductive activity. Earlier studies (Hornberger et al 2000) have shown that reproductive activity of *Macoma balthica* has increased with declining heavy metal concentration in animals from this location. Therefore, reproductive activity of *Macoma balthica* appears to be a useful indicator of physiological stress by pollutants at this location and is examined coincident with the continuing studies by Luoma on *Macoma balthica.*

The population trends of the dominant species in the benthic community will be examined to see if some species have been differentially affected by the pollutant concentrations. We will then examine the benthic community structure to see if any population changes are reflected in changes to the benthic community structure. Prior studies have shown that more opportunistic species are likely to persist in highly disturbed environments (as was shown by Nichols and Thompson (1985a) at this location in 1974 through 1983) and thus we might expect to see a shift in community composition if metal contamination has been a major disturbance factor. We might also expect to see shifts in the benthic community with changes in the concentrations of specific metals. For example it has been shown that some crustacean and polychaete species are particularly sensitive to elevated copper (Morrisey et al. 1996, Rygg 1985) and that most taxonomic groups have species that are sensitive to elevated silver (Luoma et al. 1995).

OBJECTIVES

The purpose of this study is to characterize long term trends in benthic community structure and reproductive activity of *Macoma balthica* near the discharge of the PARWQCP. These data will be used in conjunction with data collected by Luoma to achieve the following objectives:

- Provide data (1978-1990, 1998-2000) to assess seasonal and annual trends in benthic community structure at a location near the discharge (specifically at the site designated in the RWQCB's Self-Monitoring Program for PARWQCP).
- Assess seasonal and annual trends in benthic community structure (1974-2000) at a location near the discharge (specifically at the site designated in the RWQCB's Self-Monitoring Program for PARWQCP).
- Present the data within the context of historical changes inshore in South Bay and within the context of on-going monitoring of effluents.
- Provide data to assess seasonal and annual trends in reproductive activity of clams near the discharge; specifically at the site designated in the RWQCB's Self-Monitoring Program for PARWQCP.

STUDY SITE

Samples have been collected at a station located south of Sand Point (Figure 1): station FN45 is 12 m from the edge of the marsh and 110 cm above MLLW. The location of the benthic station, on a mudflat on the shore of the bay (not a slough) 1 kilometer south of the Palo Alto discharge, is influenced by the discharge of PARWQCP, but is not immediately adjacent to that discharge. Thus this location reflects a response of receiving waters to the effluent, beyond just a measure of the effluent itself. Earlier studies have shown that dyes, natural organic materials in San Francisquito Creek and waters in the PAWQCP discharge all move predominantly south toward Sand Point and thereby influence the mudflats in the vicinity of Sand Point. Earlier work by Luoma showed that San Francisquito Creek and the Yacht Harbor were minor sources of most trace elements compared to the PARWQCP.

METHODS

Samples for benthic community analysis and reproductive activity were collected using two sizes of cores during the 1974-2000 period (8.5 cm diameter x 20 cm deep; 16.5 cm x 10 cm x 23 cm deep). Two replicate samples were taken with the larger core and three replicate samples were arbitrarily taken within a 1m^2 area with the smaller core during each sampling date. There were several instances when both sizes of cores were used concurrently so we are able describe any change in variance in the data associated with core size. Samples have been collected at varying intervals (ranging from monthly to semi-annually) as shown in Appendix 1.

Samples for analysis of reproductive activity have been collected since January 1998 through December 2000 concurrently with the clam and sediment collection of the Luoma study (see Appendix 2 for dates). A minimum of 10 individual *Macoma balthica* of varying sizes (minimum of 5mm) was used in the analyses.

Laboratory Analysis

Benthic community samples were washed on a 0.5mm screen and preserved. All animals in all samples were sorted to species level where possible (some groups are still not well defined in the bay, such as the oligochaetes) and individuals for each species were enumerated by a private contractor familiar with the taxonomy of San Francisco Bay invertebrates (Susan

McCormick, Colfax, CA). S. McCormick also compared and verified her identifications with previously identified samples.

A minimum of 10 clams was processed for reproductive activity each month. Clams were immediately preserved in 10% formalin at the time of collection. The visceral mass of each clam was removed in the laboratory, stored in 70% ethyl alcohol, and then prepared using standard histological techniques: tissues were dehydrated in a graded series of alcohol, cleared in toluene (twice for one hour each), and infiltrated in a saturated solution of toluene and Paraplast for one hour, and two changes of melted Tissuemat for one hour each. Samples were embedded in Paraplast in a vacuum chamber and then thin sectioned (10 micrometer) using a microtome. Sections were stained with Harris' hematoxylin and eosin and examined with a light microscope. Each individual was characterized by size (length in mm), sex, developmental stage, and condition of gonads, thus allowing each specimen to be placed in one of five qualitative classes of gonadal development (previously described by Parchaso 1993).

Data Analysis: Methods

As stated above, the benthic community data were collected using two sizes of cores. An analysis of variance (Table 1) showed that there was no significant difference in the data for all but one species on one date after the large core data was standardized to the area of the small core. The data were examined using multivariate techniques whereby benthic population data were compared to environmental data. Environmental data (Appendix 3) included time series data, when available, of phytoplankton biomass, salinity, freshwater inflow, temperature, wind velocity (a surrogate for resuspension and erosion potential of the benthic fauna living in the shallow reaches of the bay), and body burdens of trace elements in bivalves. The reproductive stage data was similarly analyzed as a time series in conjunction with environmental data and benthic community data.

RESULTS AND DISCUSSION

Benthic Community

The simplest metrics that are used in assessing environmental stress on biological communities are estimates of species diversity and total animal abundance. Species diversity as estimated by a time series of number of species for each month showed no significant trend in this study (Figure 2) nor did total animal abundance (Figure 3). The difficulty with these types of metrics is that they do not consider the possibility that one species can take the place of another, and thus not alter the number of species or number of individuals. However, depending on the characteristics of the new species, the community structure and function may change as a result of this exchange of species. In addition, the details of changes in species composition are important as these changes may reflect the relative ability of species to accommodate environmental stress. As will be shown below, examining these details was very important in attaining our objectives with this data set.

Time series plots of the abundance of several species are shown here. We start with three common bivalves that did not show any consistent trend over the 26-year period (Figures 4, 5, and 6). In all cases, there is significant seasonal and inter-annual variability in species abundances. The next three plots are of three species that did show trends in their abundance throughout the study. The first species, *Ampelisca abdita*, is a small crustacean that lives above the surface of the mudflat in a tube that they build from selected sediment particles. There was a general decline in this species over the period of the study, with both the annual abundance averages (see below) and annual maximum abundances as seen in Figure 7 declining. The

second species to show a significant trend was the small polychaete worm *Streblospio benedicti* (Figure 8), which also builds a tube above the surface of the mudflat. As with *A. abdita*, this worm has shown a decline in seasonal maximum abundances as well as annual average abundances. The only species to show an increase in abundance through the time series was the polychaete worm *Heteromastus filiformis* (Figure 9), a burrowing species that lives deep in the sediment (usually 5-20 cm below the surface of the mudflat).

The multivariate analyses of the population data of the dominant species with the environmental parameters (Appendix C) did not reveal any relationships except with the concentration of silver and copper in the sediment and in the tissue of *Macoma balthica* (using Luoma data as most recently reported by David et al. 2002). The deposit-feeding worm *H. filiformis* has increased in abundance with the decrease in copper and silver as shown in the comparison of metal and population abundance time series data (Figure 10). The natural spatial variability (i.e. the large standard deviations around the monthly means) and the seasonal variability in invertebrate abundance and metal concentration can be quite large as seen in these plots. Thus, the annual average abundances and metal concentrations are also shown in Figures 11 and 12. To interpret these plots, we must first examine the life history characteristics of this species and determine if there is some mechanism by which this organism could be responding to a decrease in silver or copper in the environment. *H. filiformis* has continual tissue contact with the sediment both at the exterior of it's body as well as within it's body due to its life style of burrowing through the sediment and it's diet which is composed of mud and organic particles that it encounters in the mud. In addition, this is one of the few species in the present community that reproduces exclusively by laying it's eggs in the sediment, where juvenile worms, upon hatching, crawl directly into the surrounding mud. Thus one hypothesis for *H. filiformis'* increase in abundance may be that either the adult worms or the eggs are less stressed in the present environment. Because of it's mode of reproduction, this species is not likely to move into an area quickly after the environment becomes acceptable, so it is not possible to identify either the identity of the metal and or the threshold concentration of the metal to which the animal is responding without laboratory tests. However, other investigators have shown that silver can adversely effect reproduction in invertebrates and that adult *H. filiformis* can tolerate high levels of copper Ahn et al. 1995). The gradual increase in *H. filiformis* abundance through 1984 may be a response to the gradual reduction of metals in the environment or may indicate that it took several years for the population to build up in the area. The large abundance increase in 1985 and 1986, followed by a decline and leveling out of abundance, may be an example of the "boom and bust" principle whereby a species rises to levels too high for the habitat to support, and declines in abundance until it levels out to what becomes their normal, habitat-supportable, abundance. It is unclear, based on only two years of data in the late 1990's, if this species has established a stable abundance.

The two species that have declined in abundance coincident with the decline in metals, the crustacean *A. abdita* (Figures 13, 14 and 15) and the worm *S. benedicti* (Figures 16, 17 and 18), have very similar life history characteristics. Both live on the surface of the sediment in tubes that are built from sediment particles, are known as opportunistic species and are thus capable of rapid expansion of their distribution, rapid growth in abundance of their populations, brood their young, and produce young that are capable of both swimming or settling upon hatching. It is unclear why these species have become less competitive in the present day environment but their very low numbers in the last two years indicate that this is a major shift in the community as both species were numerically very dominant in the benthic community in the 1970's and 1980's. We have also shown plots of another species, the small clam *Gemma gemma* (Figures 19, 20, and 21) that reproduces by brooding their young and lives on the sediment surface. Unlike *A. abdita* and *H. filiformis*, there has been no significant decline in the abundance of *G. gemma*.

Rank abundance plots can be a useful tool in evaluating the structural changes in species dominance. The relative abundances of the dominant species are displayed as a function of their

rank in the community (rank of one being the most dominant). A community is most stable when the relative abundances of the species are similar – i.e. the curve is flat. We show rank abundance curves (Figure 22, from Shouse 2002) for the communities in the period prior to the decline in metal concentrations (1977) and in a year after the decline in metal concentrations (1989). These years and months were chosen because of their similar rainfall history since changes in salinity can re-structure a benthic community. We can see that the dominant three species in the 1977 curve are greatly more abundant than the remaining species of the community. This changed dramatically in 1989 when we see a curve that is close to horizontal and thus more indicative of a stable community. To illustrate how this community has changed we have indicated the functional group or life history traits of the species on the curves. The combination of rank, abundance, and life history traits suggests that the community has not only become more stable, but of the four most abundant species, there has been a shift so that two of the four present species burrow in the sediment, consume particles in the sediment, and reproduce by laying their eggs in the sediment (the mixed reproduction strategy species is one that can asexually reproduce or reproduce by laying eggs). In contrast, the 1977 benthic community was dominated by species that lived on the surface of the sediment or in tubes on the surface and brooded their young.

Reproduction of Macoma balthica

As seen in previous years (Hornberger et al. 1999), reproduction in *Macoma balthica* continues to reflect the concentration of silver found in the tissue of this clam. The time series of reproductive activity (Figure 23) shows that *M. balthica* continues to be highly reproductive relative to the 1970's with a high percentage of the animals being reproductively active at any one time and with normal seasonal cycling of reproduction occurring in spring and fall (see Appendix B for details of the last three years of data). Unlike the earlier periods, animals do not stay reproductively inactive for longer than a month or two.

Value of Long Term Monitoring

Both portions of this study show the value of long-term monitoring that incorporates seasonal sampling. Changes and trends in community structure that may be related to anthropogenic stressors such as was seen in this study, can only be established given a study of sufficient length in time and frequency of sampling that the natural stressors can be characterized and separated from those introduced by man.

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	Mar-80		Jan-83		May-83		Aug-83		Feb-84	
	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
Ampelisca abdita	6.765	0.080	6.690	0.081	1.800	0.272	0.006	0.944	0.252	0.650
Gemma gemma	0.557	0.510	0.862	0.422	4.742	0.118	1.236	0.347	0.075	0.802
Heteromastus filiformis	0.005	0.947	1.300	0.337	2.032	0.249	0.096	0.786	3.583	0.155
Macoma balthica	0.587	0.499	4.624	0.121	0.648	0.480	0.001	0.980	5.511	0.101
Streblospio benedicti	0.107	0.766	11.665	**0.042**	0.064	0.817	5.714	0.097	0.256	0.647

p<=0.05 means there is a significant difference between the two sampling methods

Table 1. Analysis of variance between the two core sizes collected during 5 months for the dominant species.

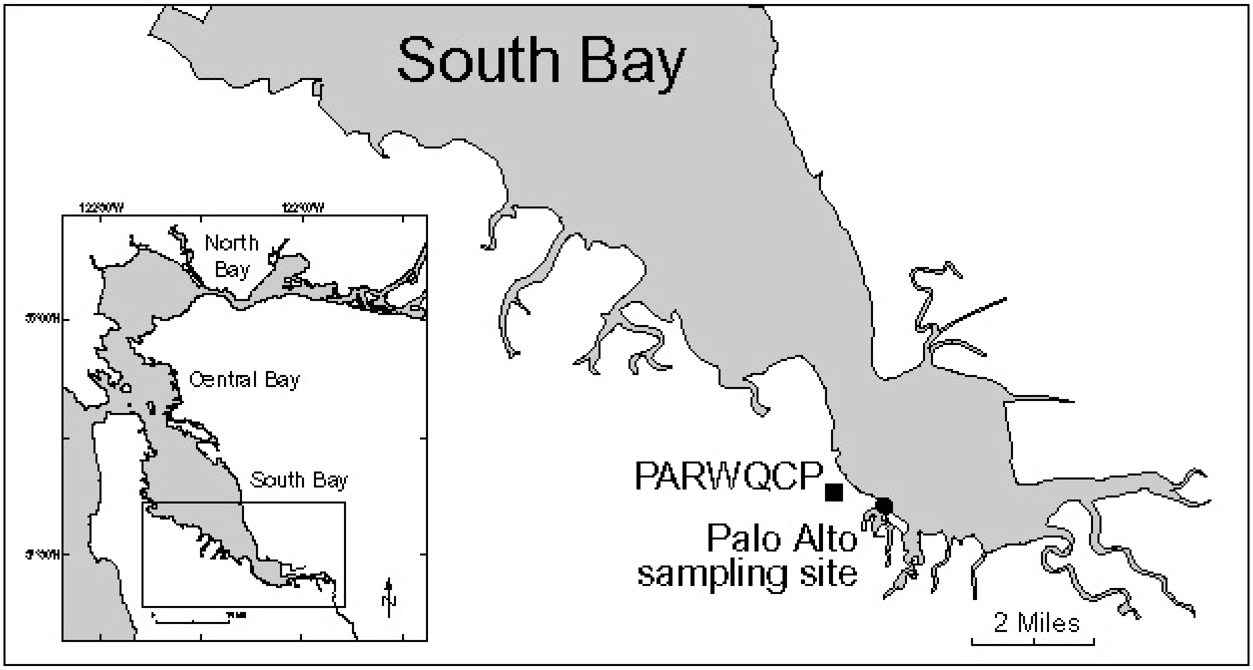


Figure 1. Map of sampling station at Palo Alto in South San Francisco Bay with location of Palo Alto Regional Water Quality Control Plant (PARWQCP) noted.

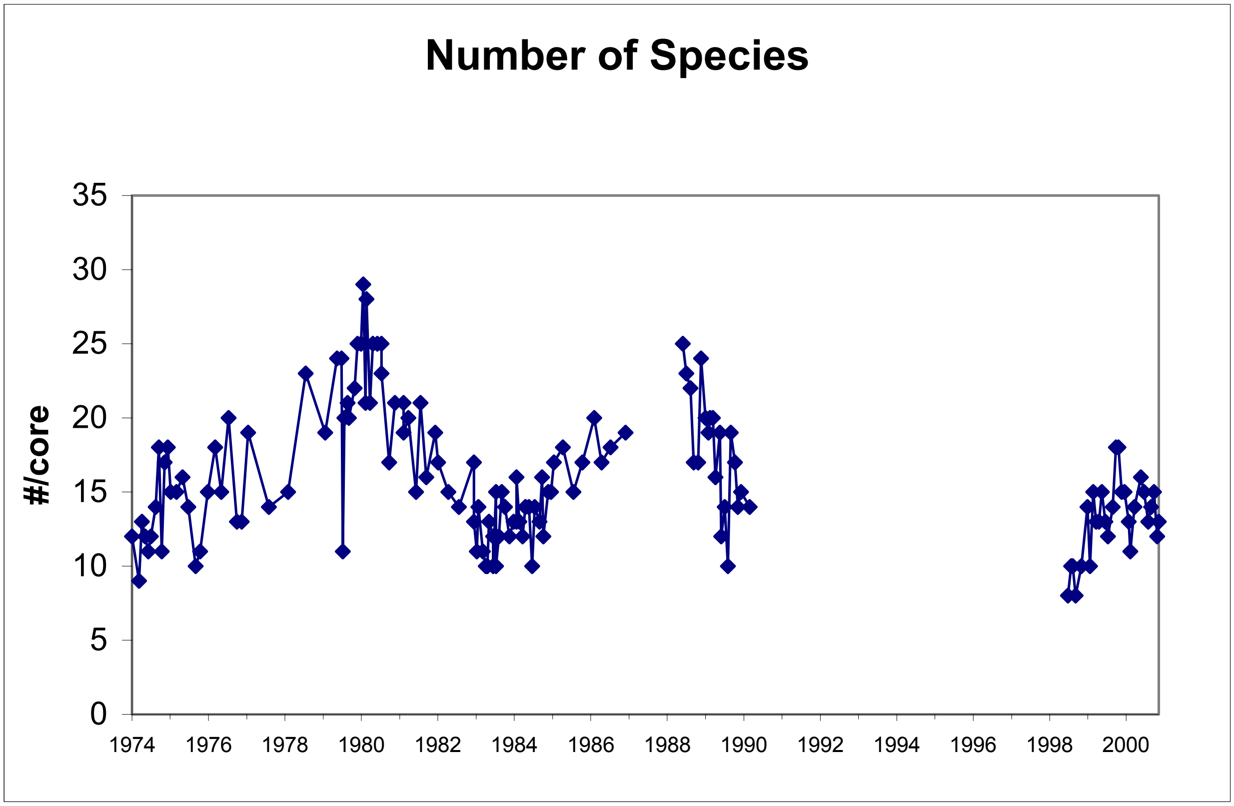


Figure 2. Average number of species in each sample period (1974-2000)

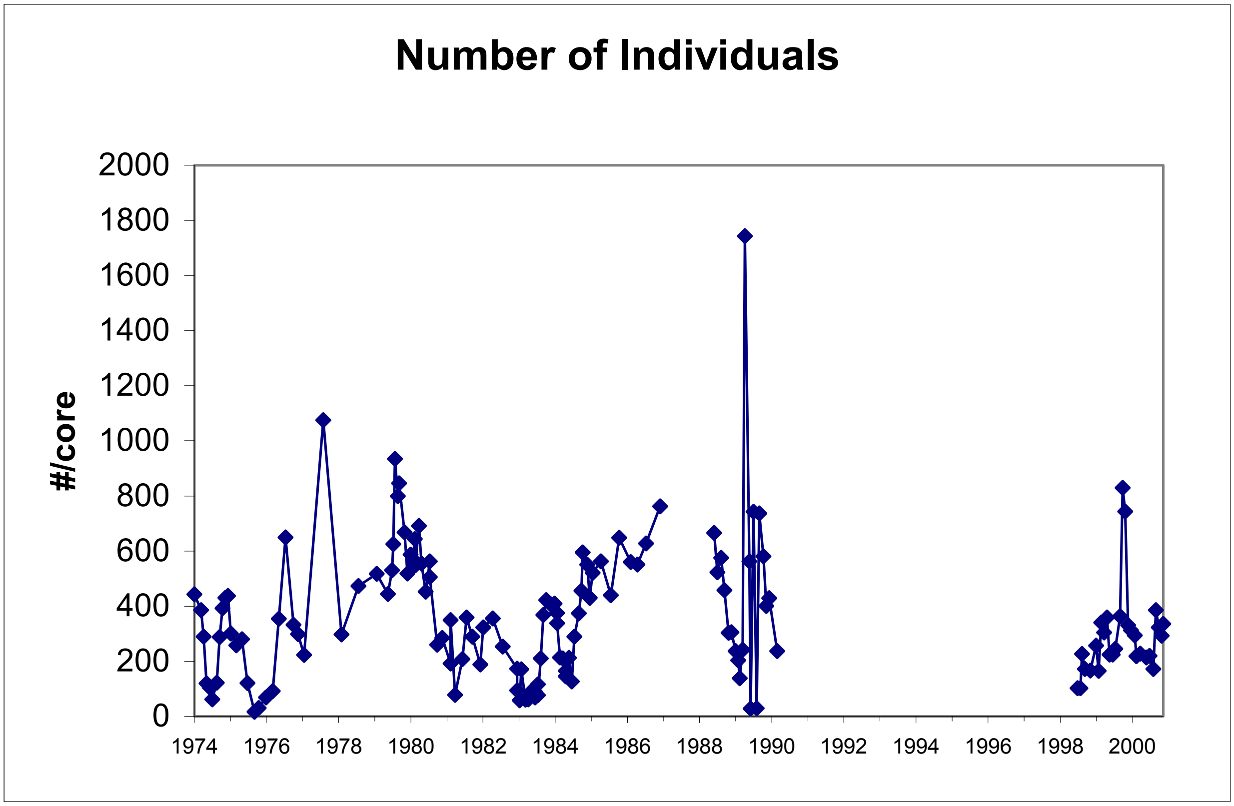


Figure 3. Total number of individuals in each sample period (1974-2000)

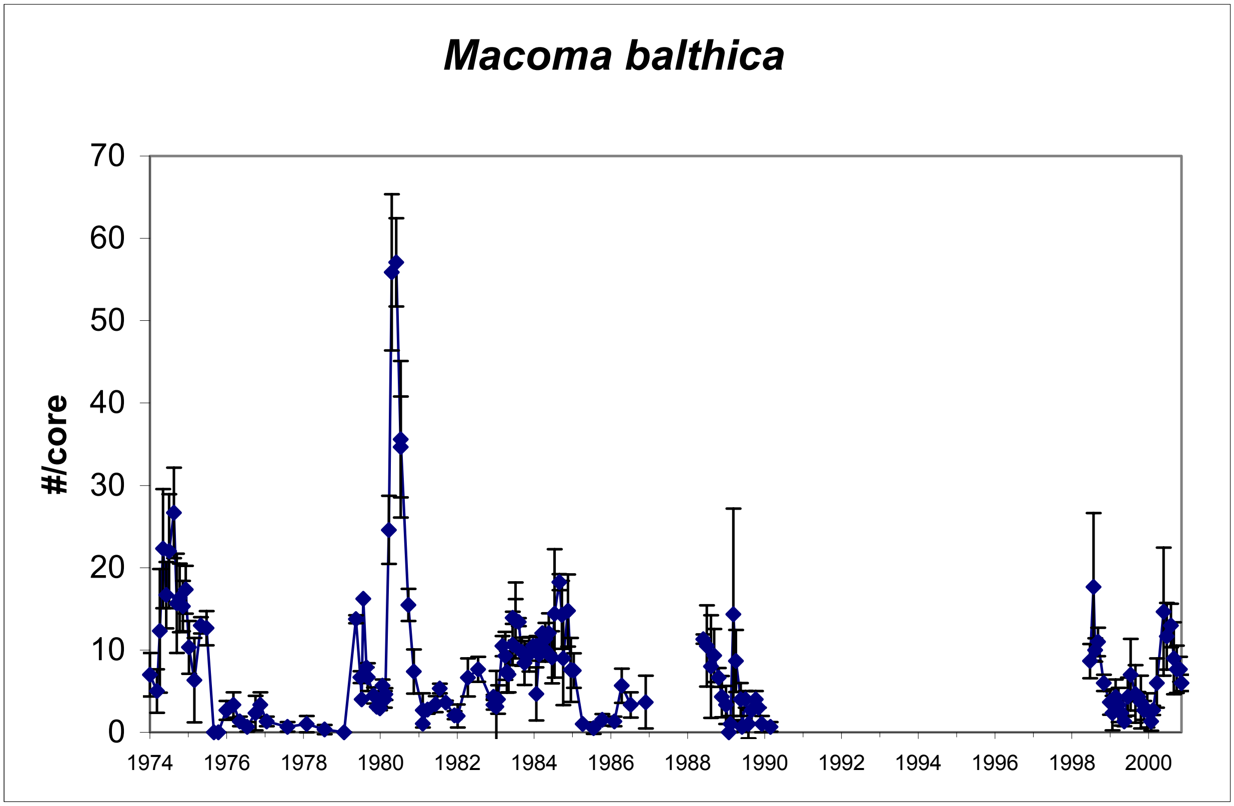


Figure 4. Average abundance and standard deviation of *Macoma balthica* (1974-2000)

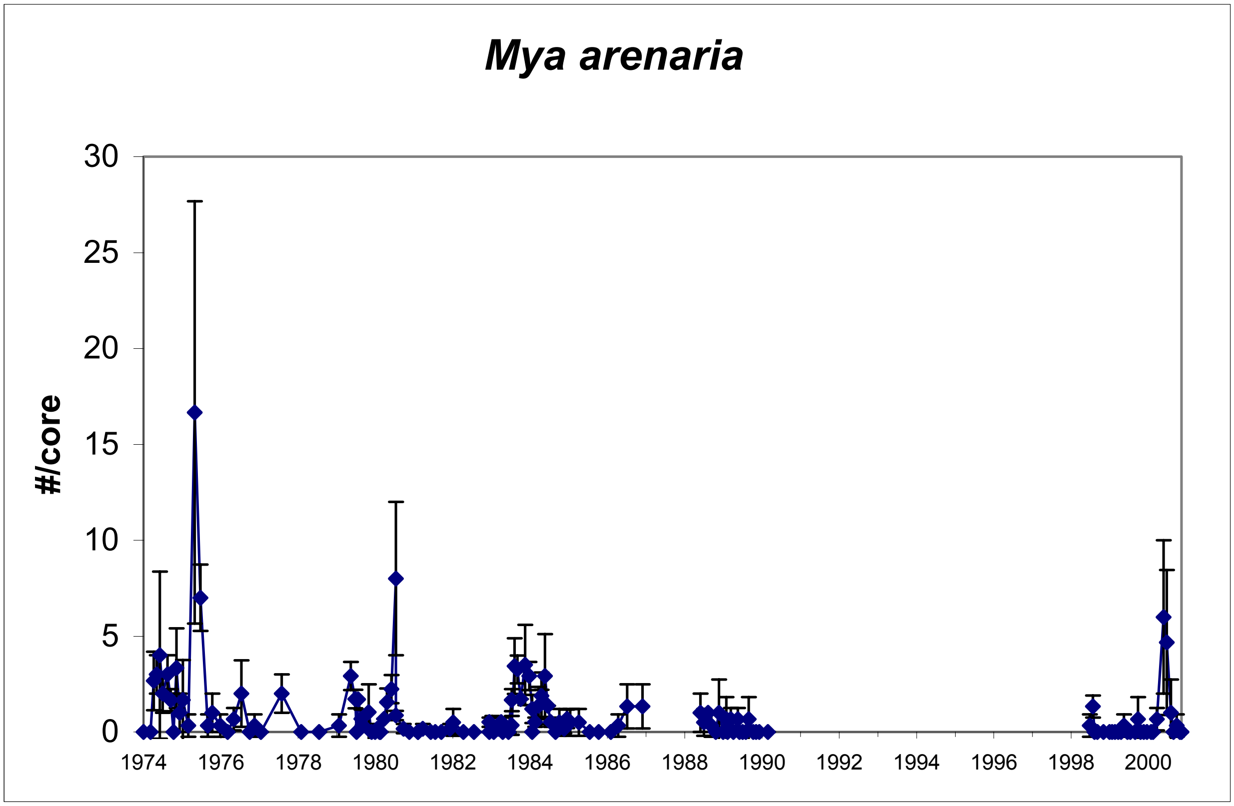


Figure 5. Average abundance and standard deviation of *Mya arenaira* (1974-2000)

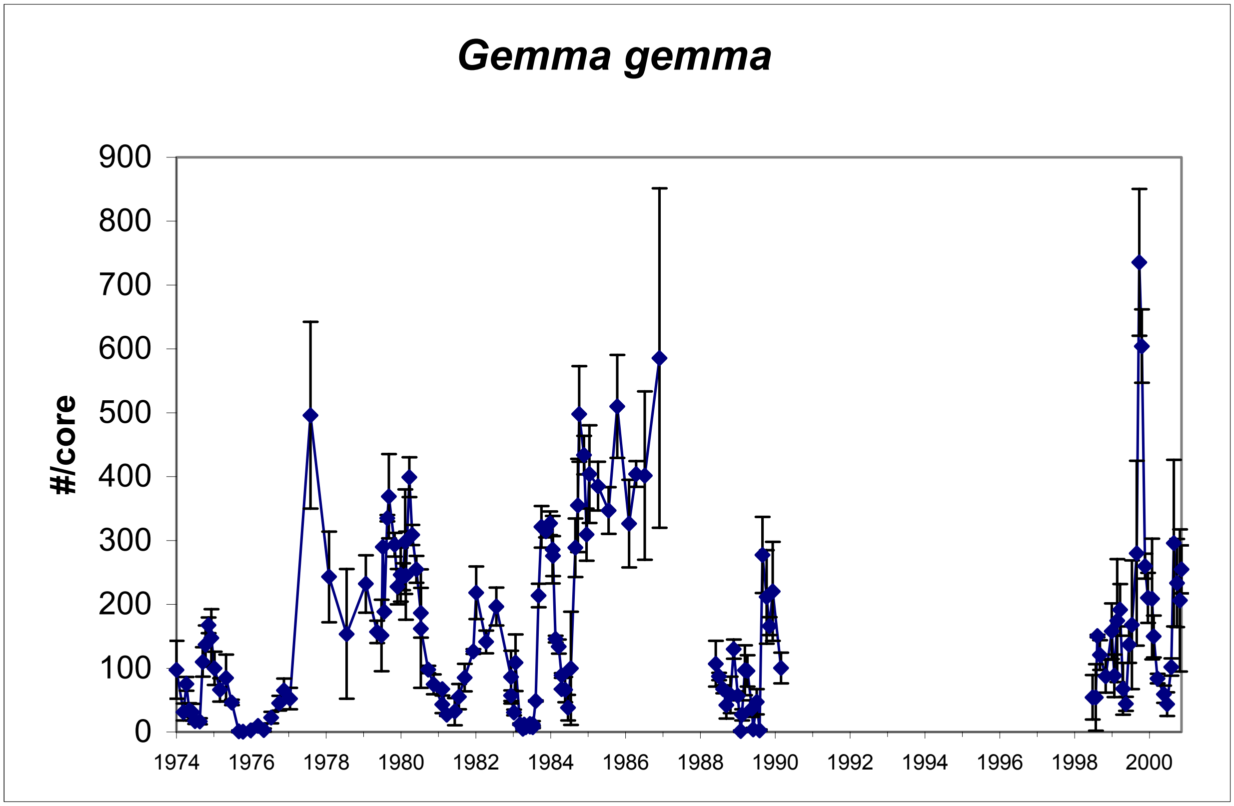


Figure 6. Average abundance and standard deviation of *Gemma gemma* (1974-2000)

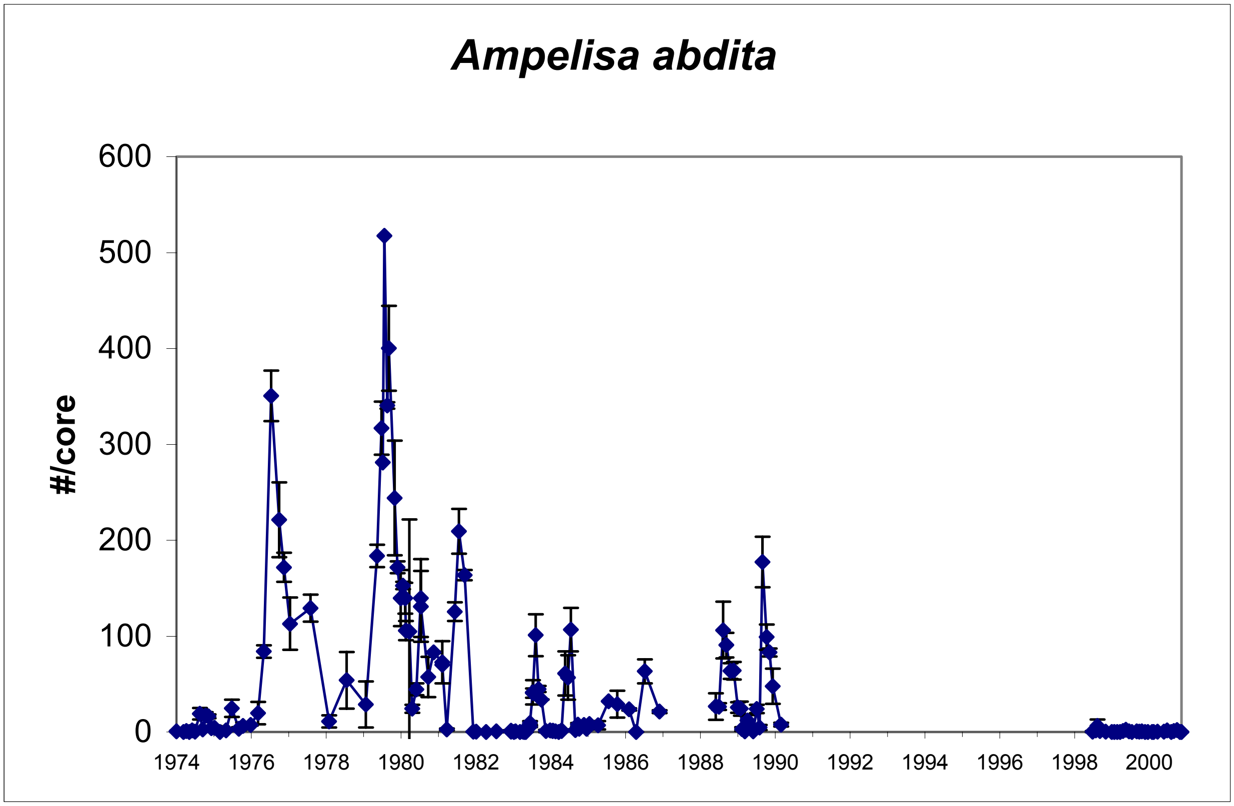


Figure 7. Average abundance and standard deviation of *Ampelisca abdita* (1974-2000)

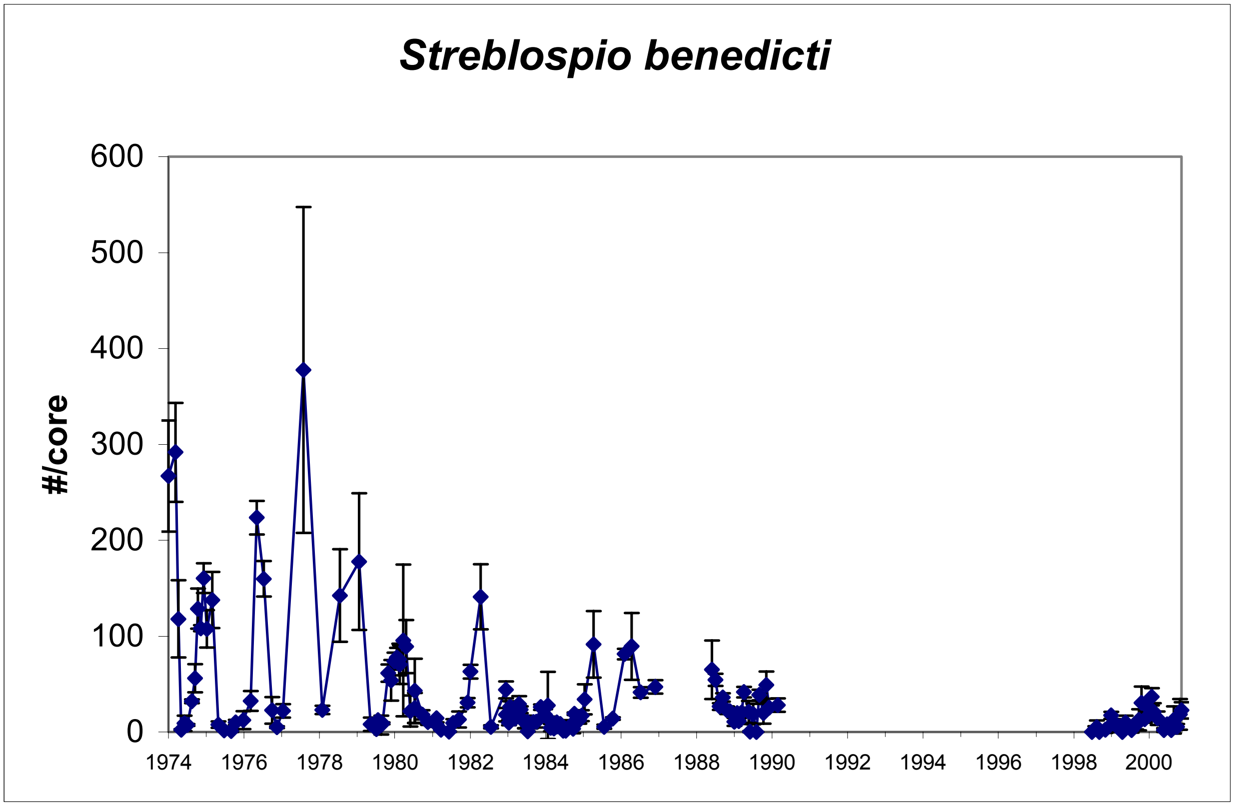


Figure 8. Average abundance and standard deviation of *Streblospio benedicti* (1974-2000)

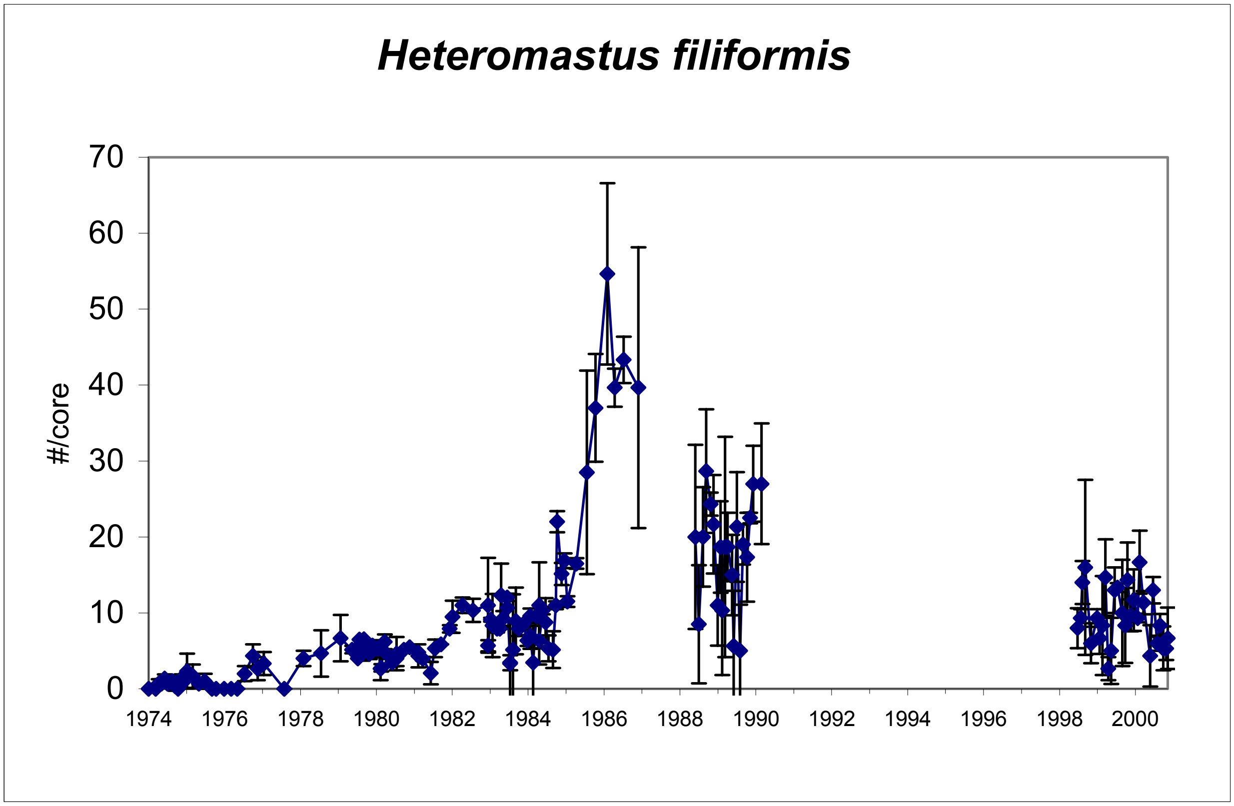
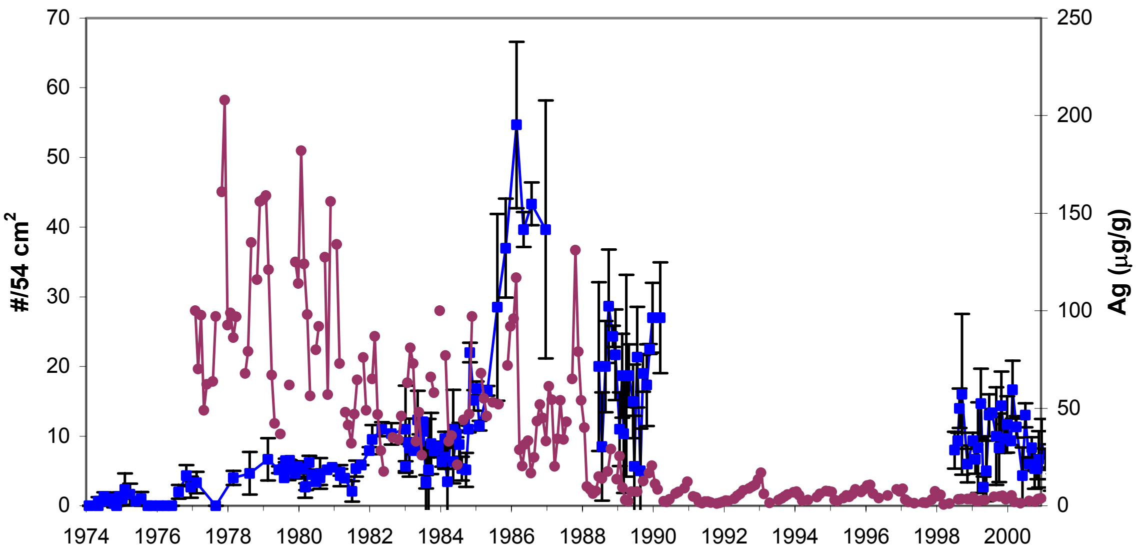


Figure 9. Average abundance and standard deviation of *Hetermastus filiformis* (1974-2000)

Silver Concentration in *Macoma balthica* and *Heteromastus filiformis* Abundance



Copper Concentration in *Macoma balthica* and *Heteromastus filiformis* Abundance

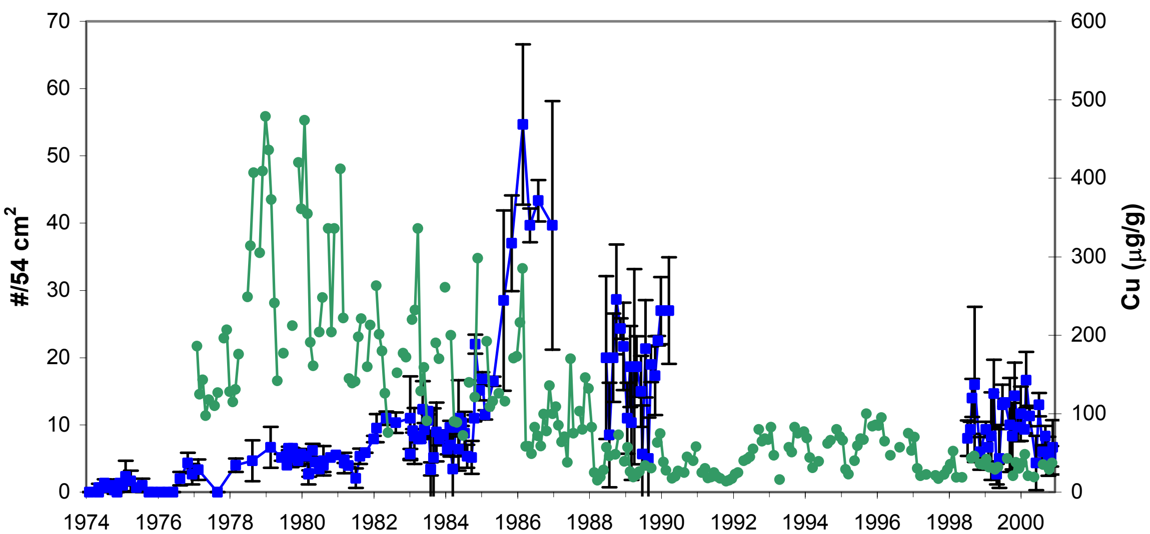


Figure 10. Time series of *Heteromastus filiformis* abundance with silver and copper tissue concentrations in *Macoma balthica*

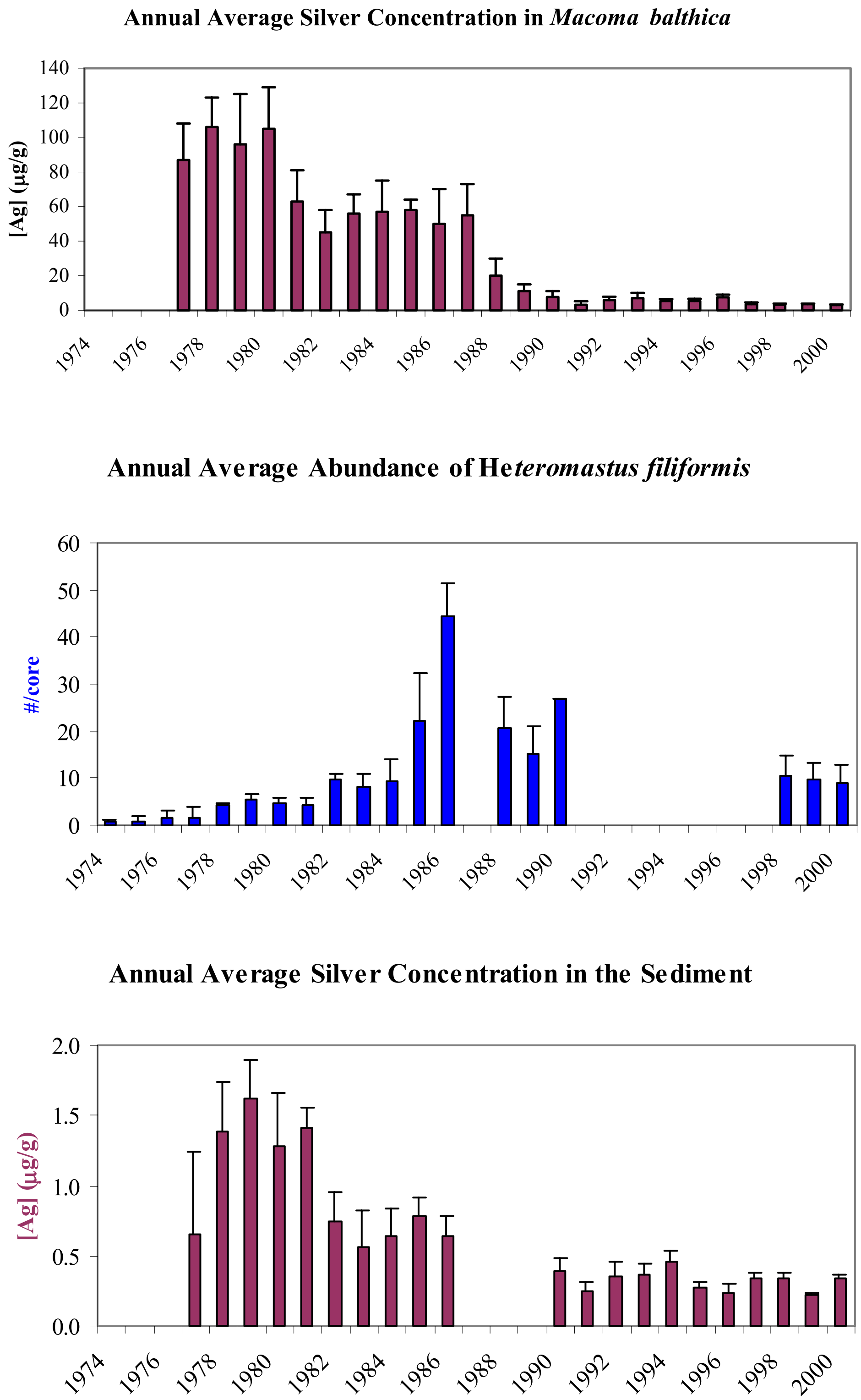


Figure 11. *Heteromastus filiformis* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

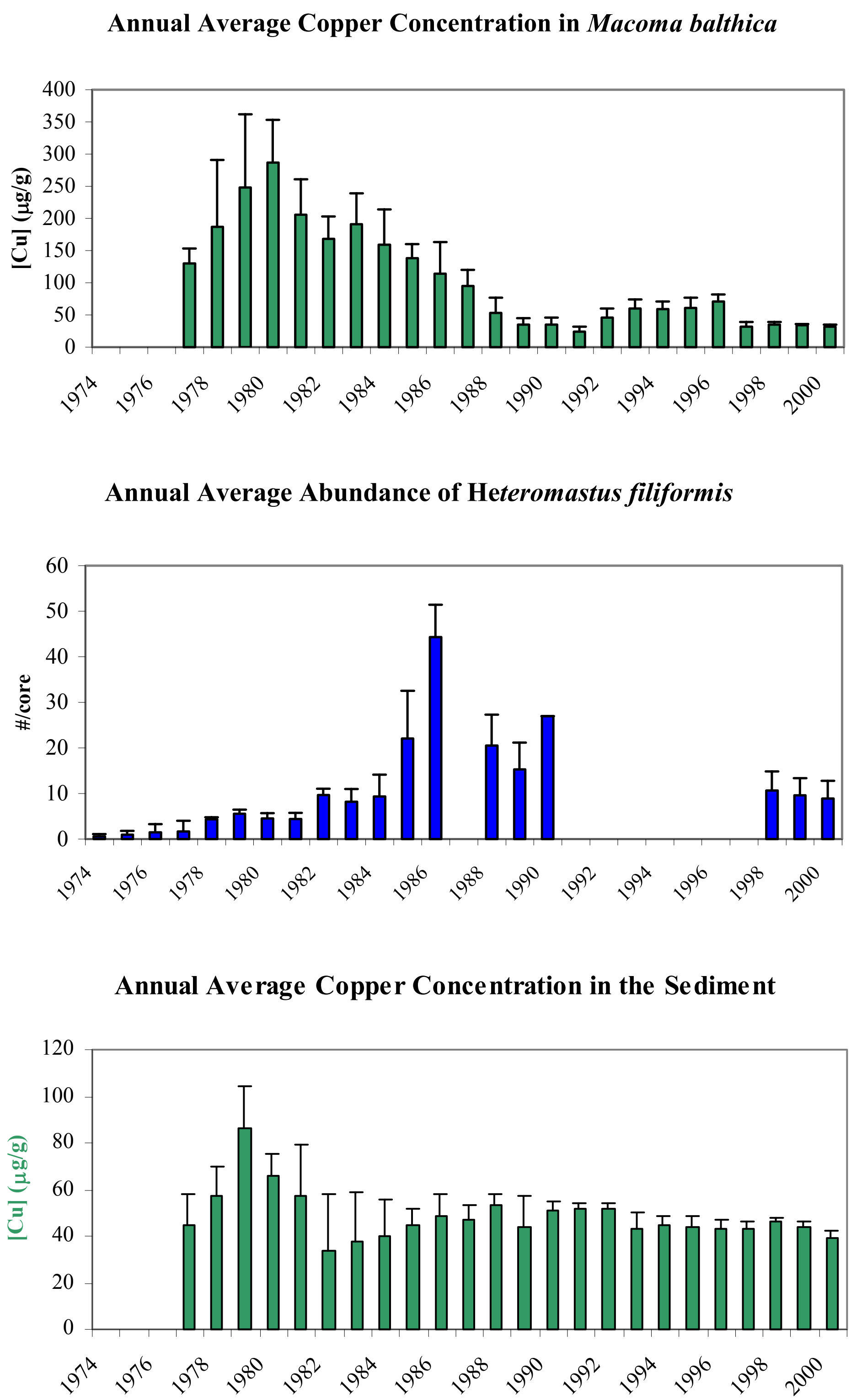
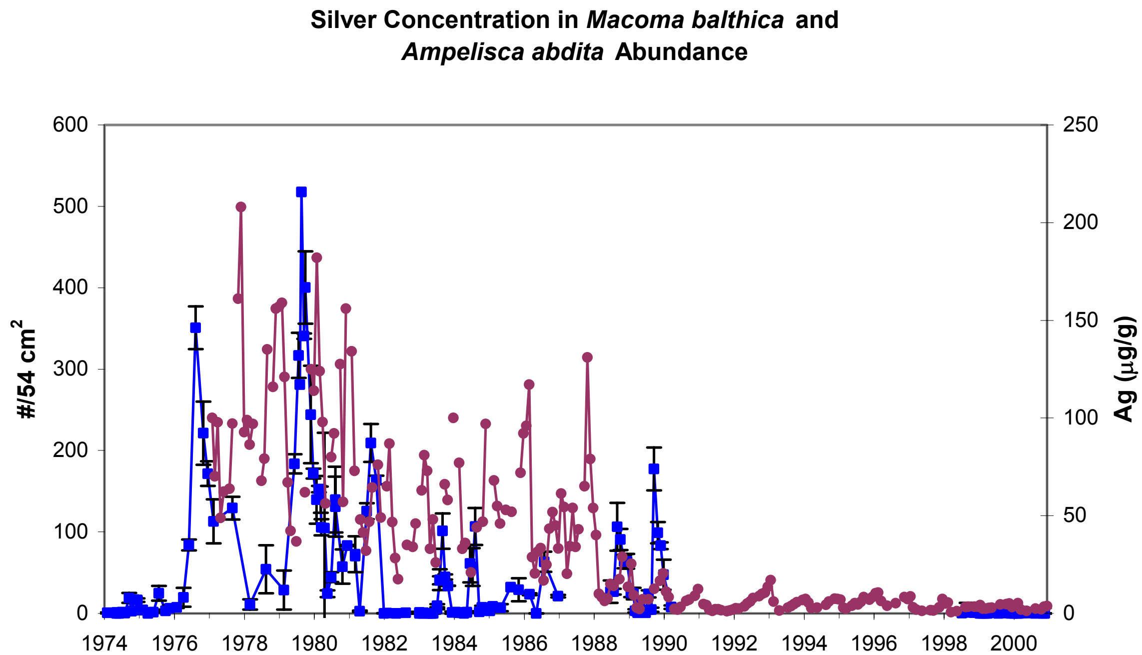


Figure 12. *Heteromastus filiformis* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment



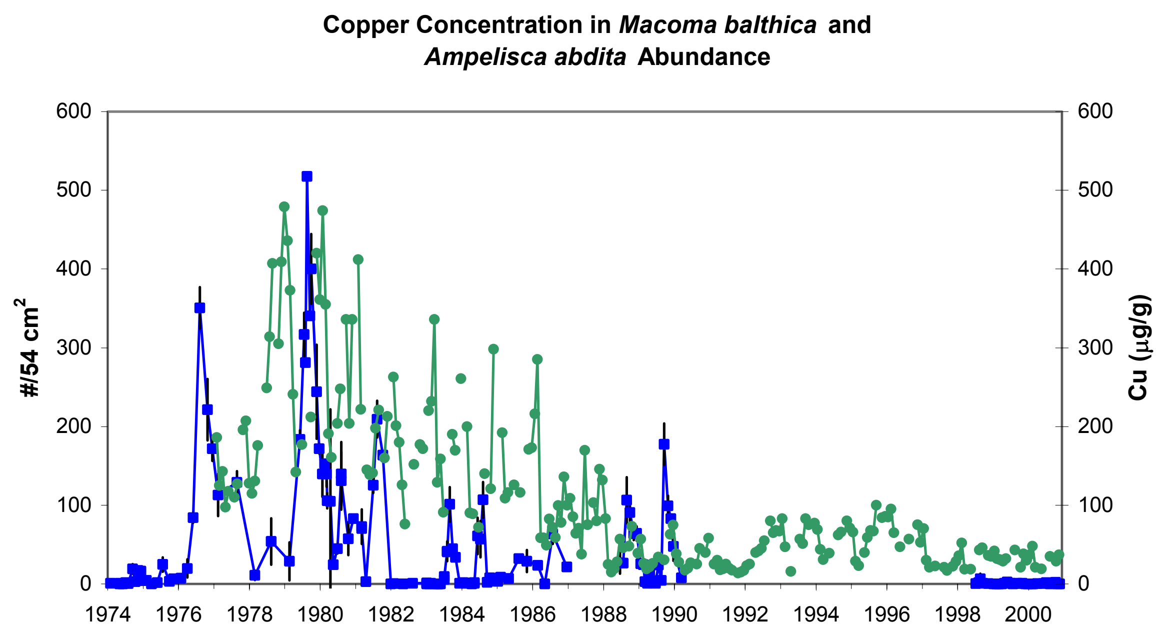
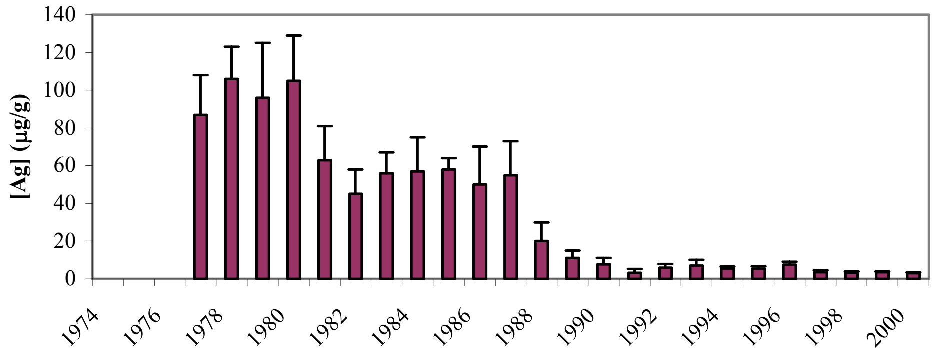
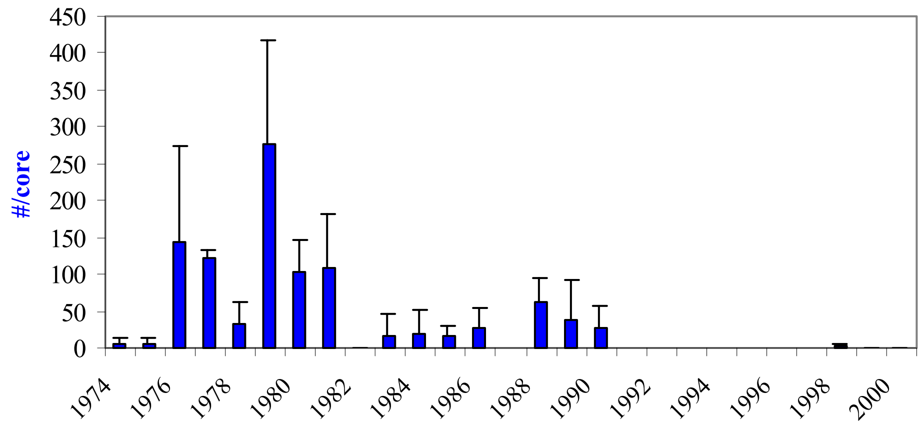


Figure 13. Time series of *Ampelisca abdita* abundance with silver and copper tissue concentrations in *Macoma balthica*

Annual Average Silver Concentration in *Macoma balthica*



Annual Average Abundance of *Ampelisca abdita*



Annual Average Silver Concentration in the Sediment

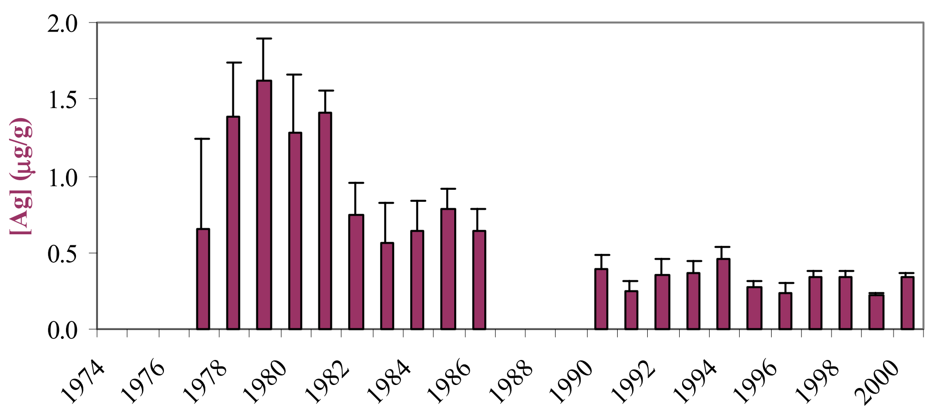
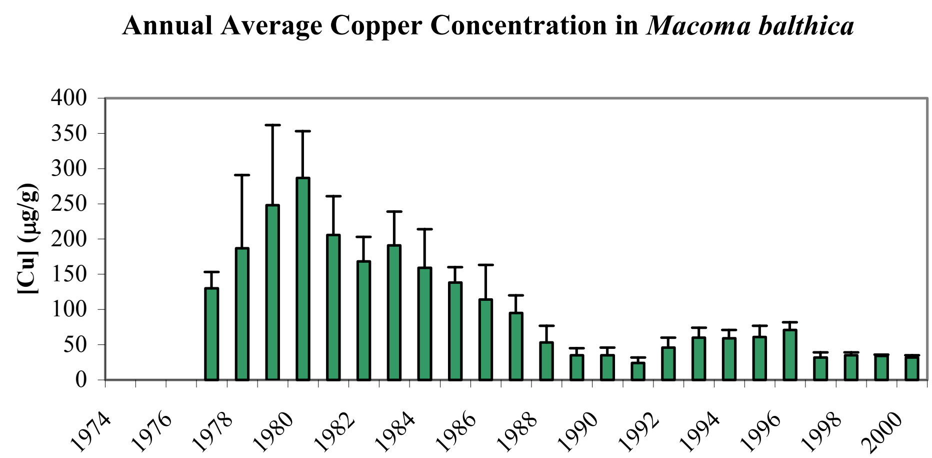
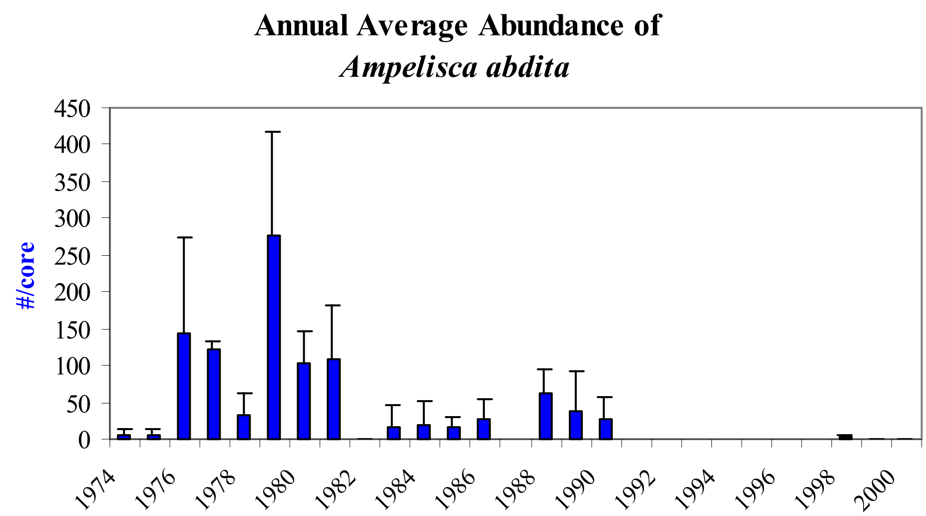


Figure 14. *Ampelisca abdita* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment





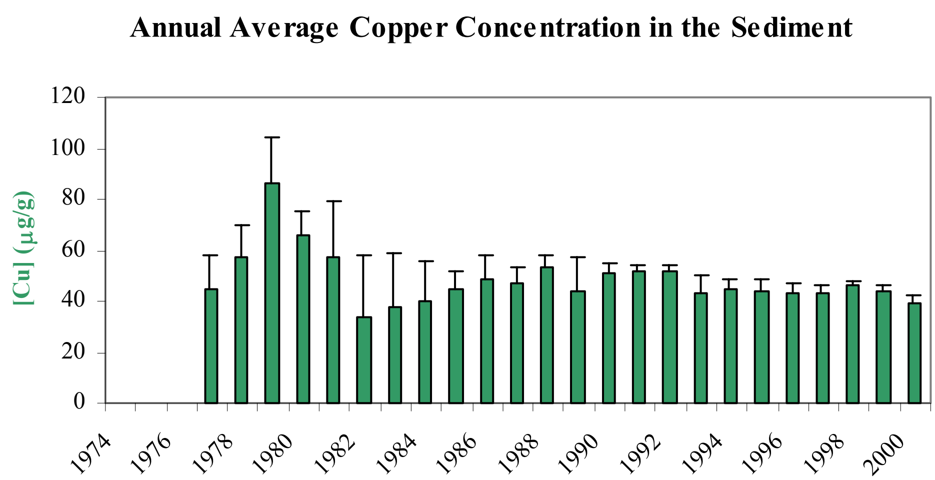
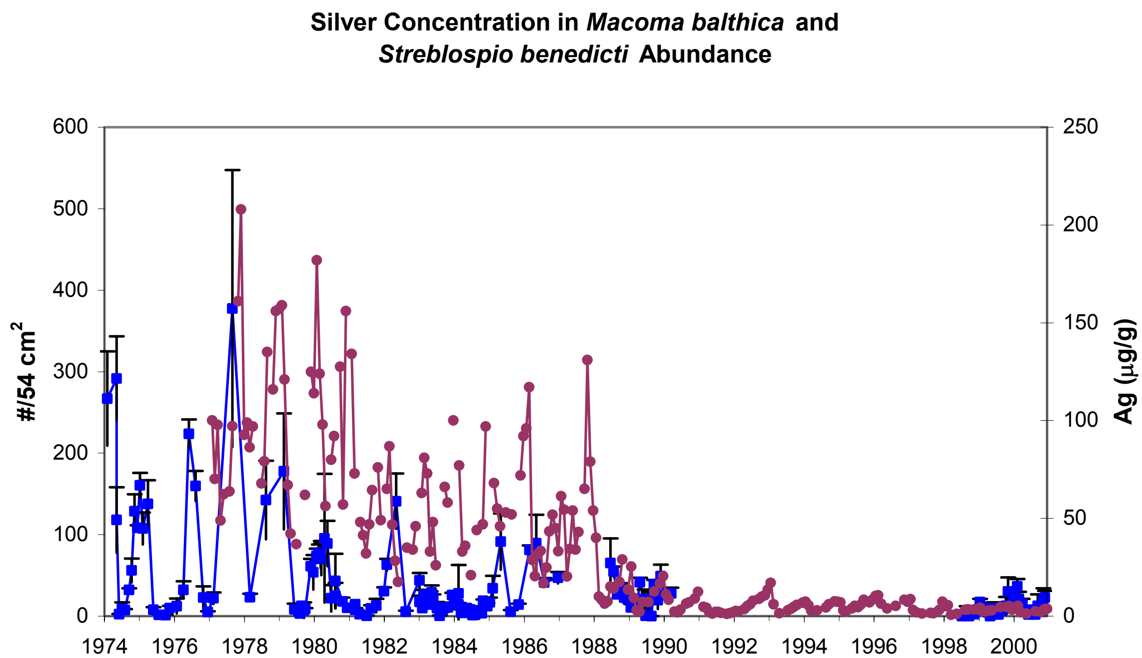


Figure 15. *Ampelisca abdita* annual abundance with copper concentrations in *balthica* tissue and in sediment



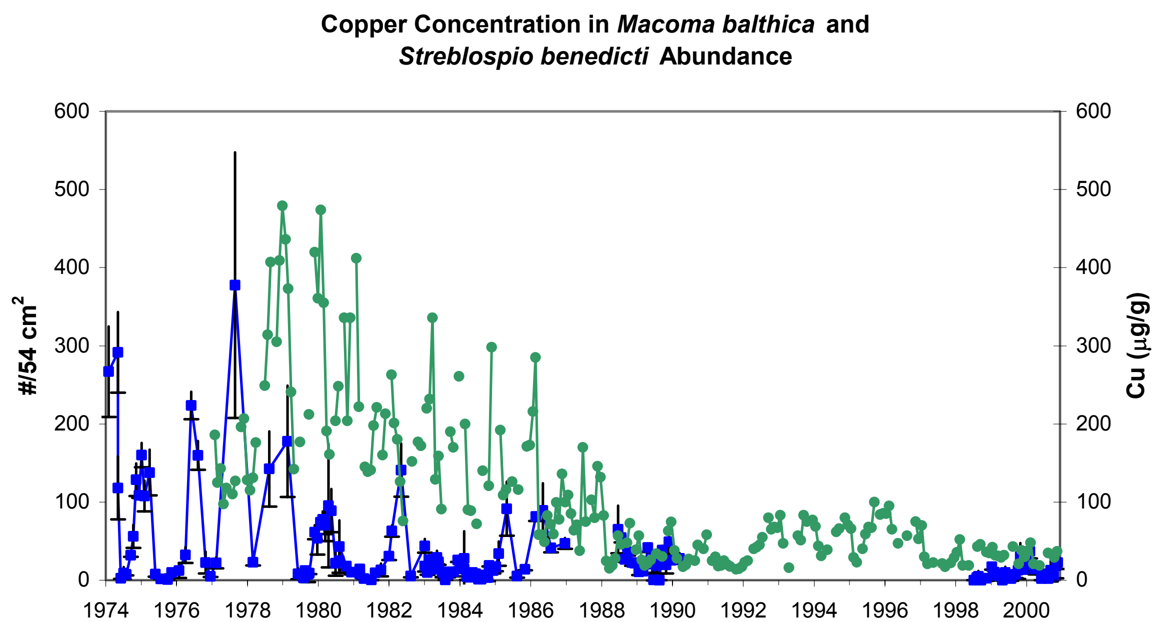


Figure 16. Time series of *Streblospio benedicti* abundance with silver and copper tissue concentrations in *Macoma balthica*

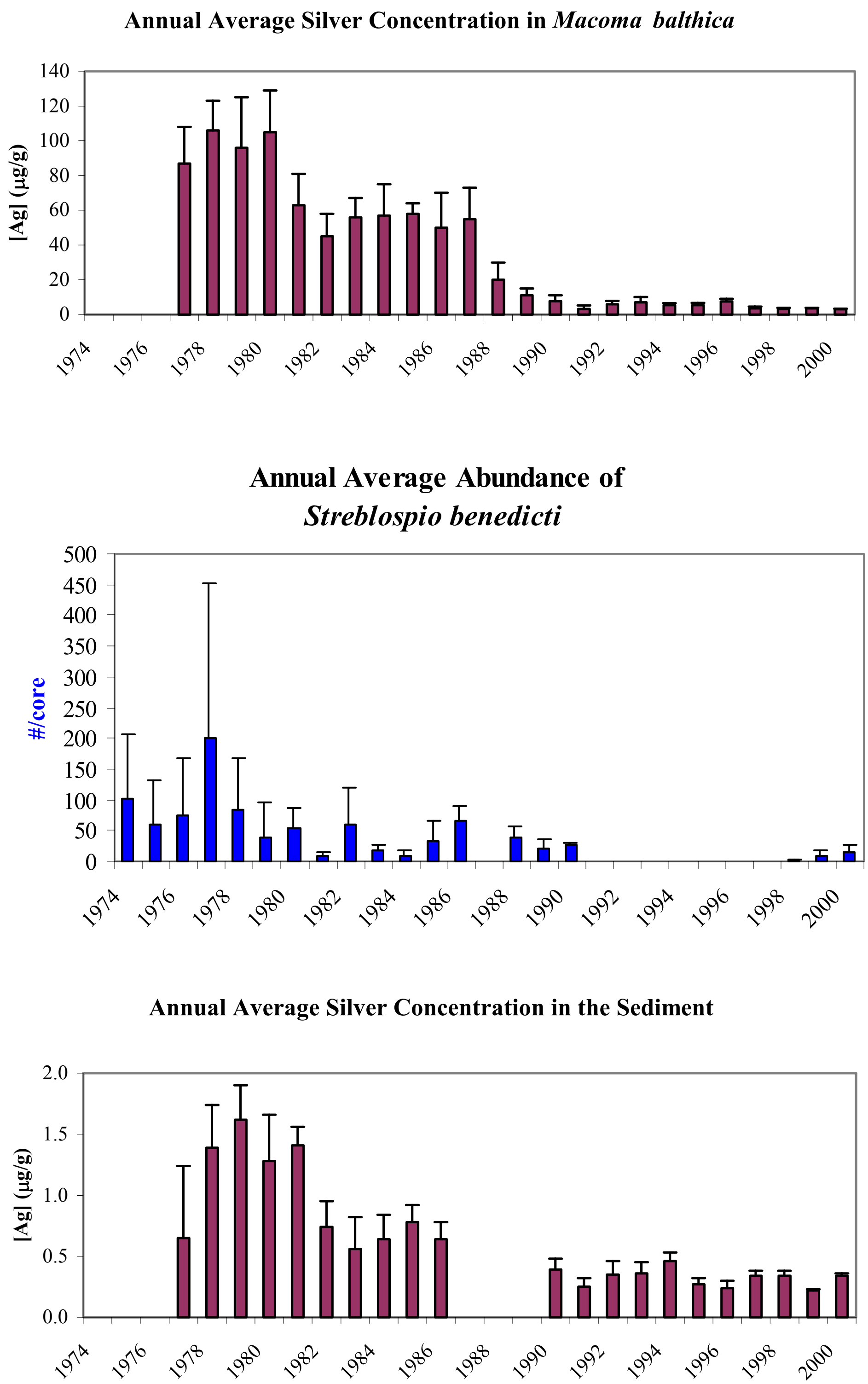
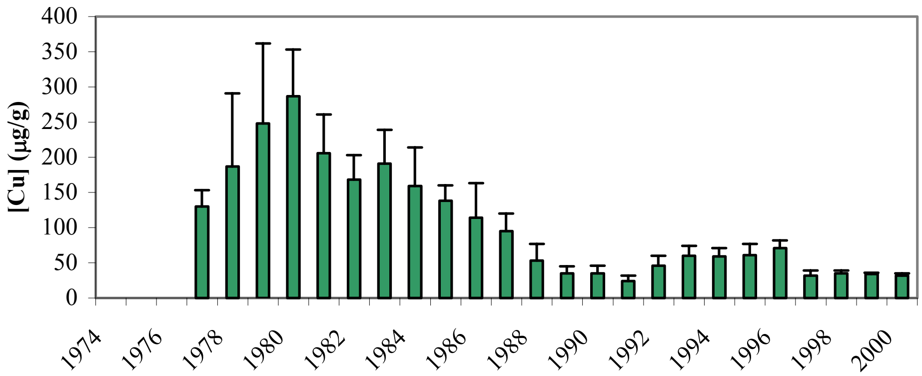
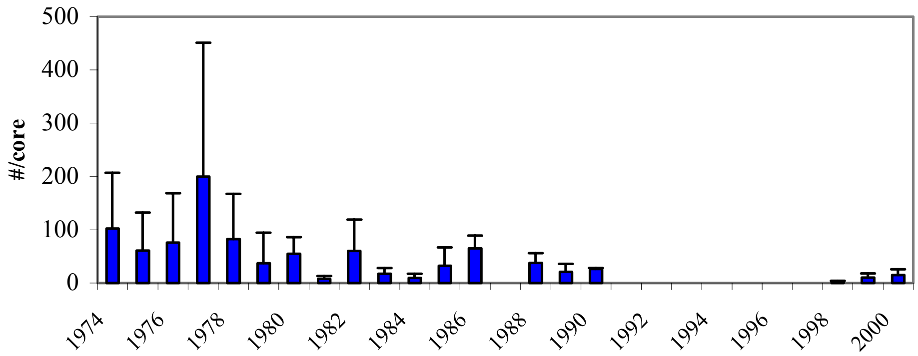


Figure 17. *Streblospio benedicti* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

Annual Average Copper Concentration in *Macoma balthica*



Annual Average Abundance of *Streblospio benedicti*



Annual Average Copper Concentration in the Sediment

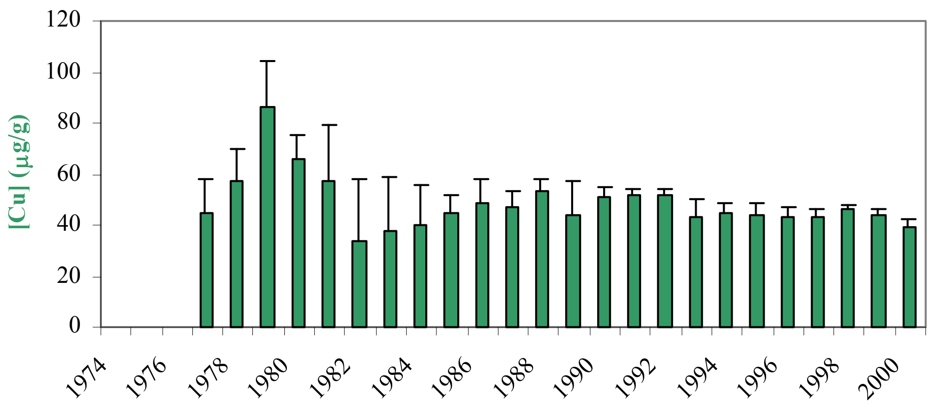
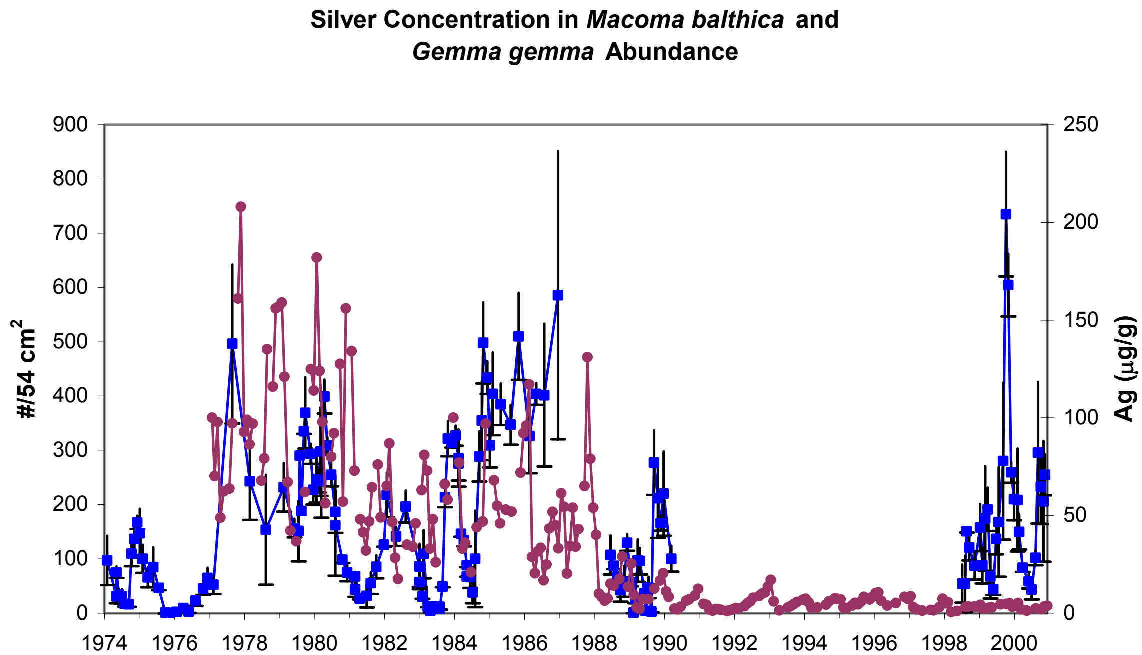


Figure 18. *Streblospio benedicti* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment



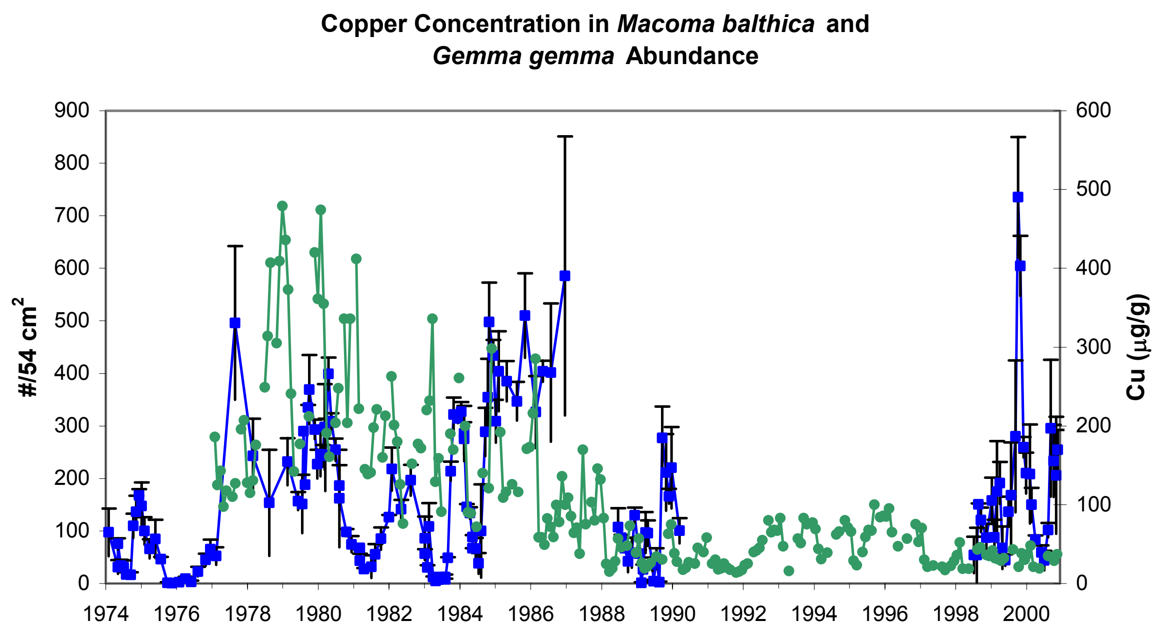
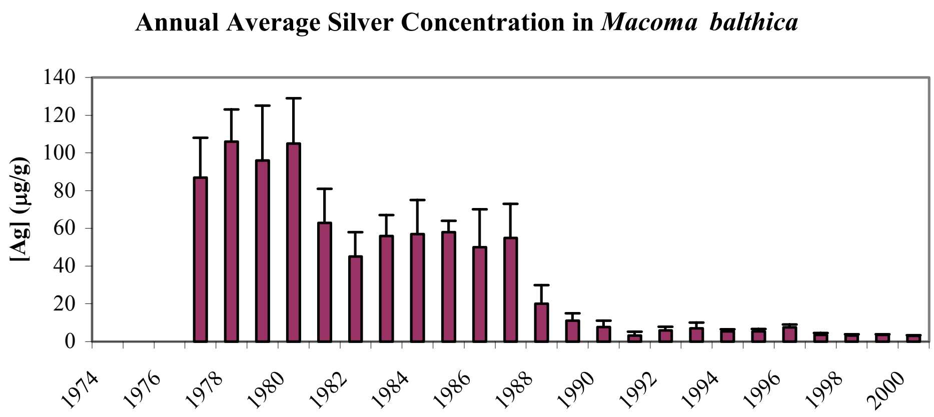
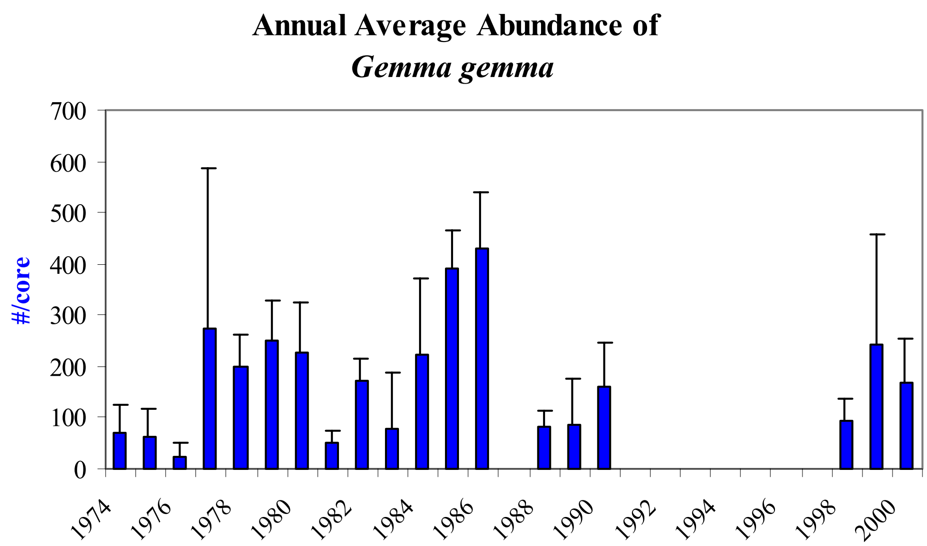


Figure 19. Time series of *Gemma gemma* abundance with silver and copper tissue concentrations in *Macoma balthica*





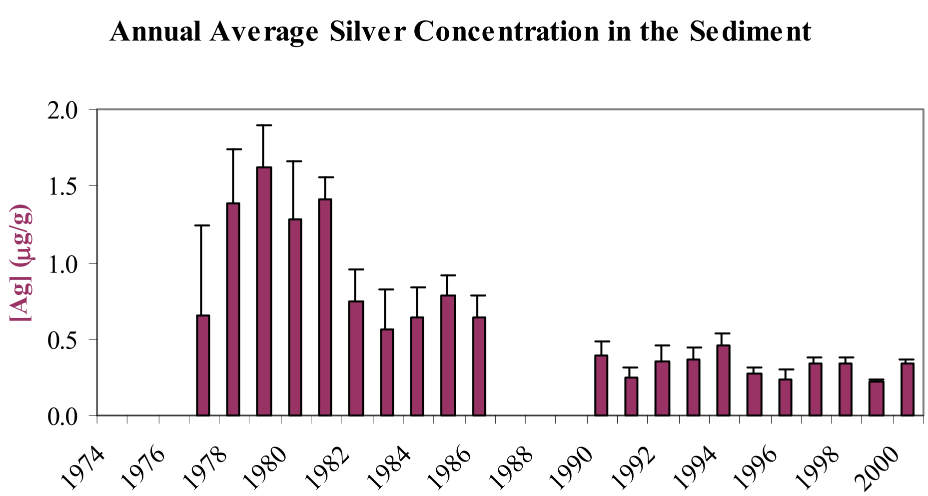
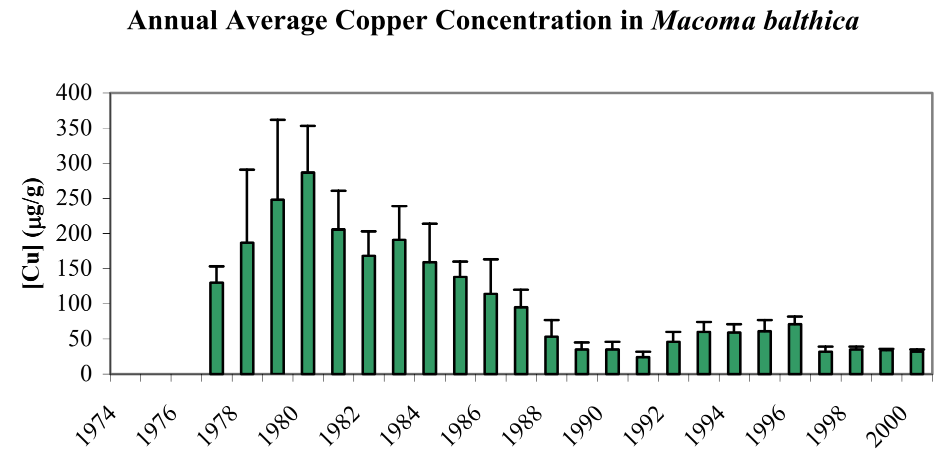
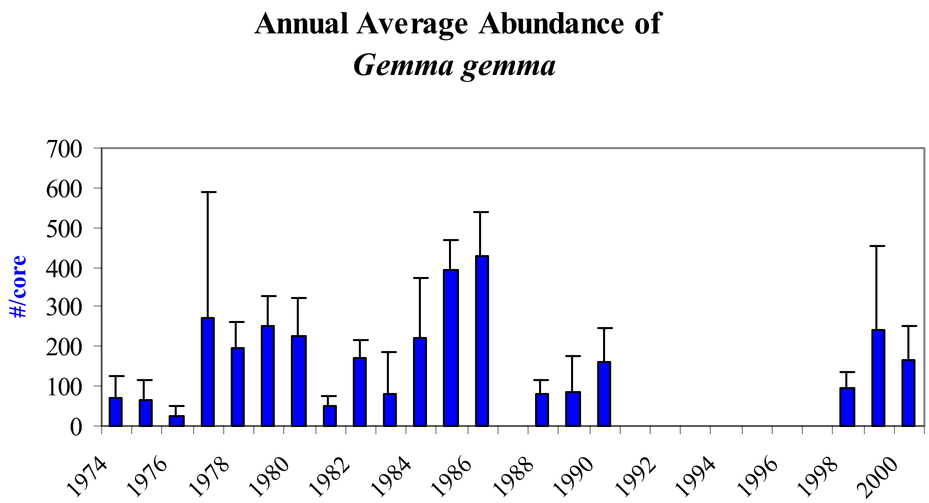


Figure 20. *Gemma gemma* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment





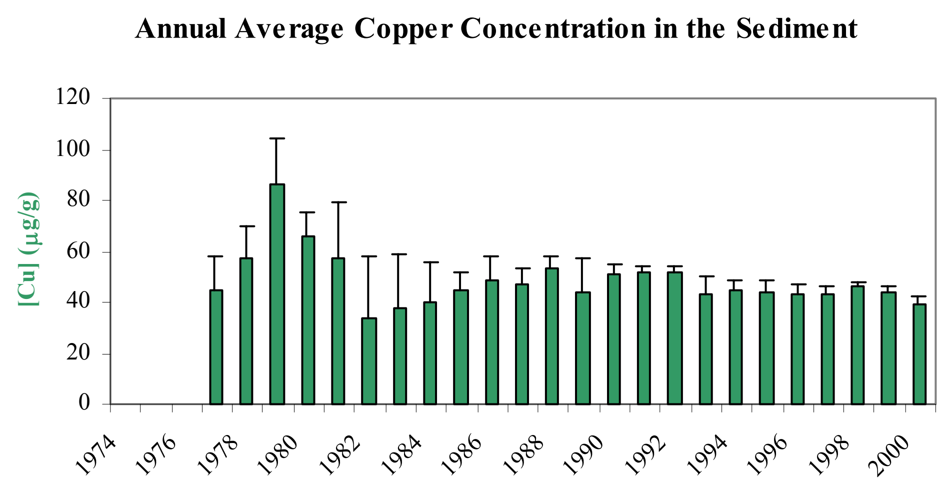
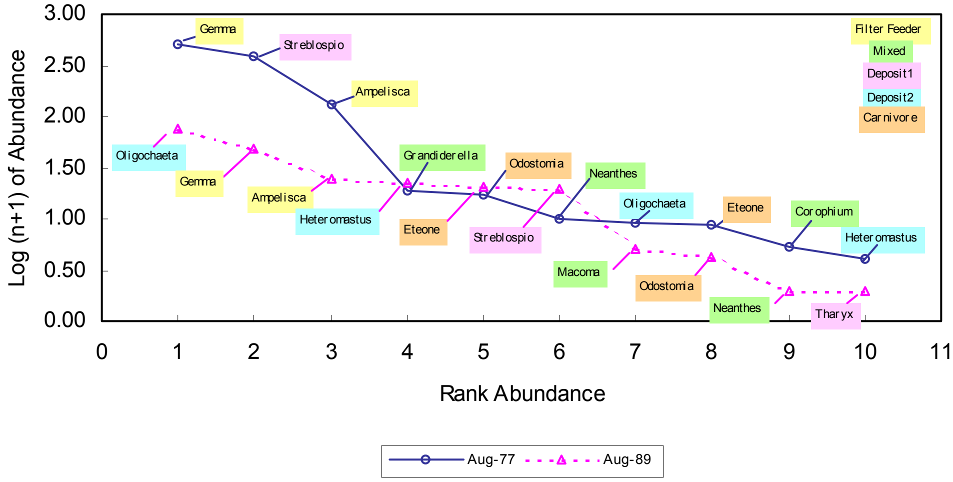
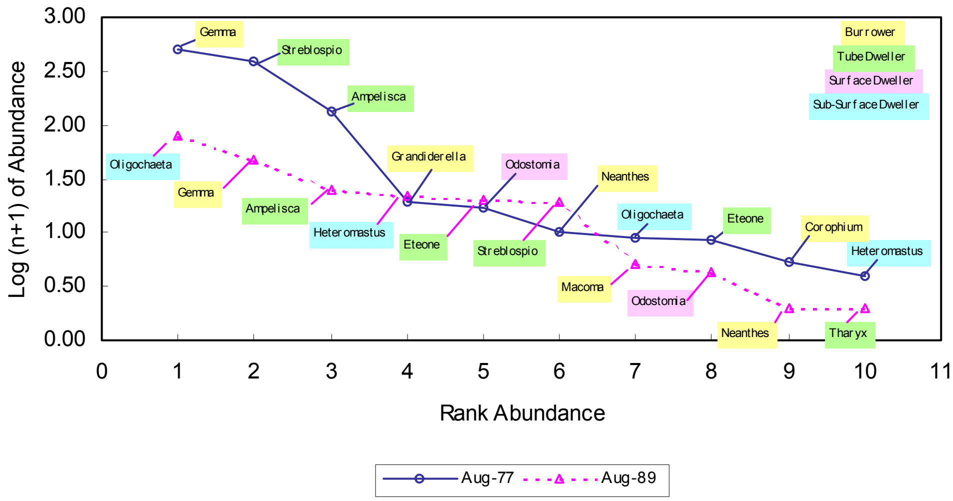


Figure 21. *Gemma gemma* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment





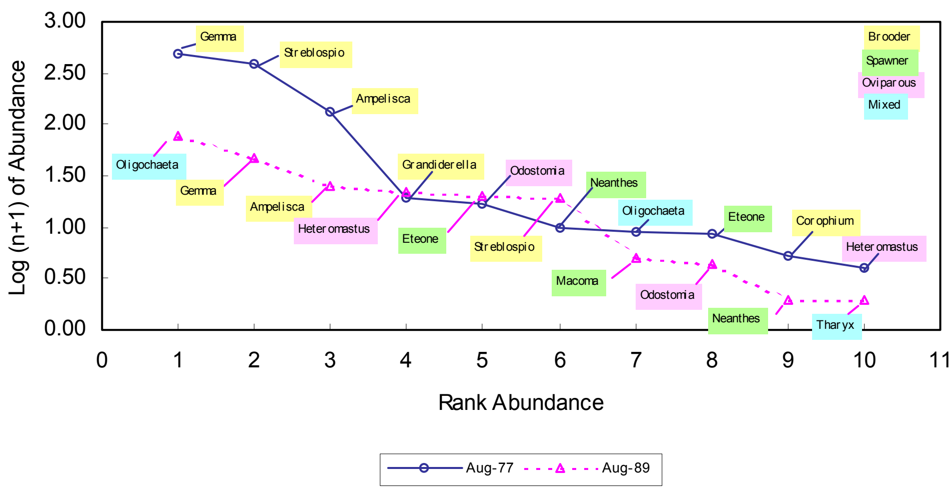


Figure 22. Rank abundance plots for major functional groups

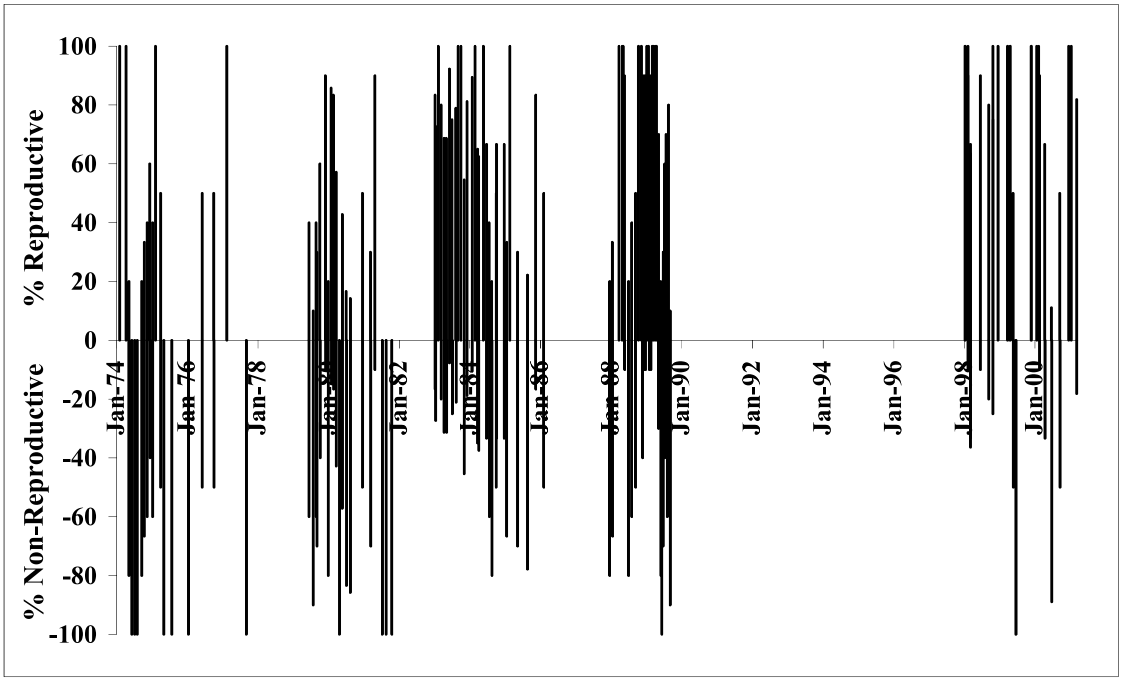


Figure 23. Reproductive activity of *Macoma balthica* (1974-2000

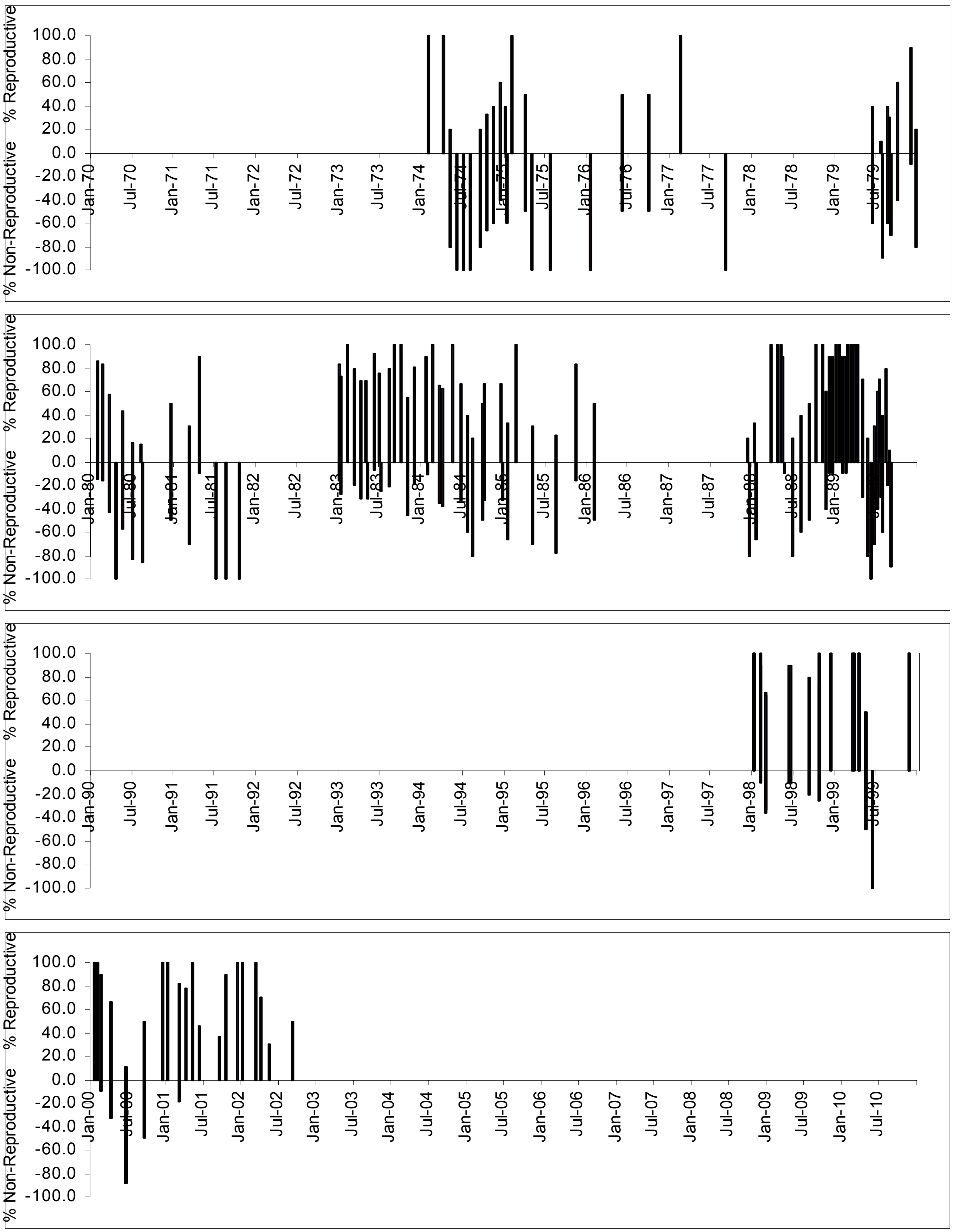
APPENDIX 1: PALO ALTO BENTHIC COMMUNITY

(*data from larger core that have been standardized to the area of the smaller core)

See attached Excel file: Appendix 1

APPENDIX 2: PALO ALTO *MACOMA BALTHICA* REPRODUCTION

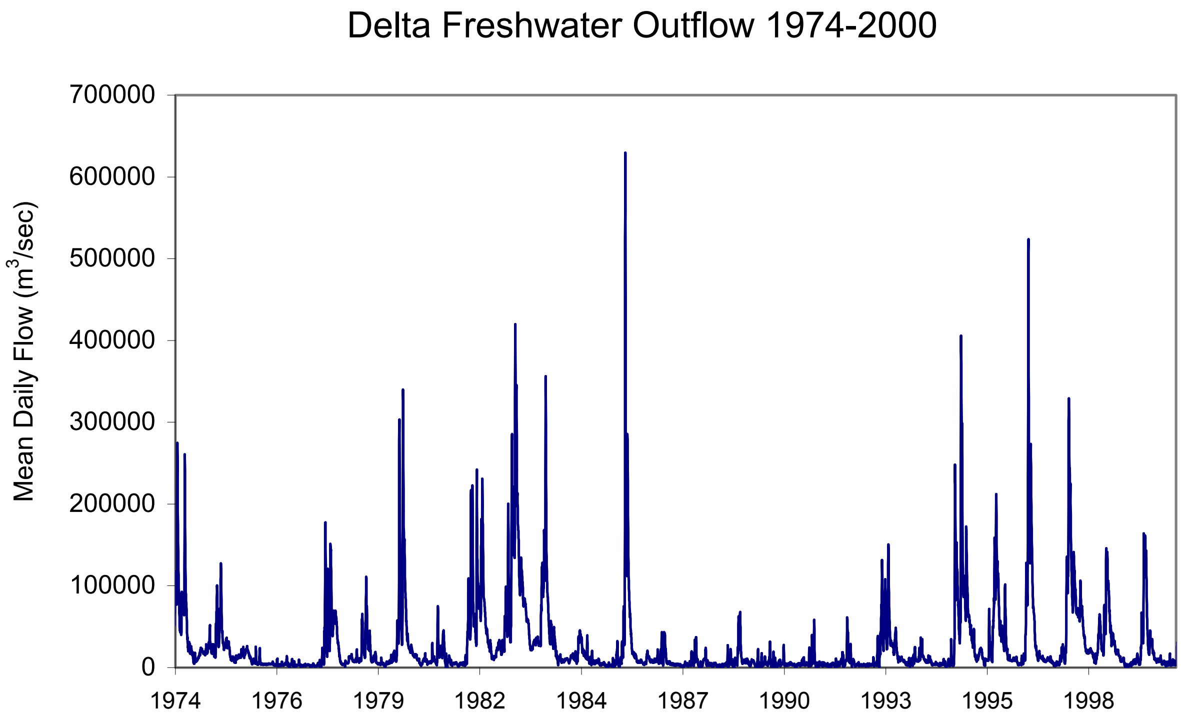
See attached Excel file: Appendix 2

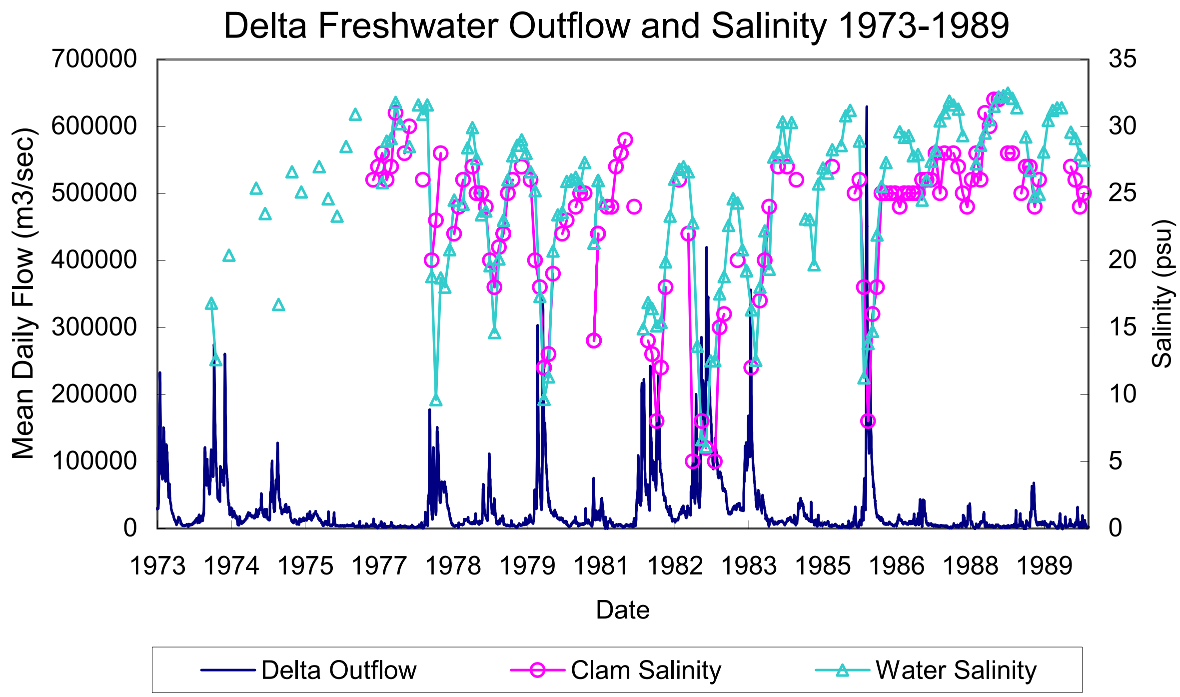


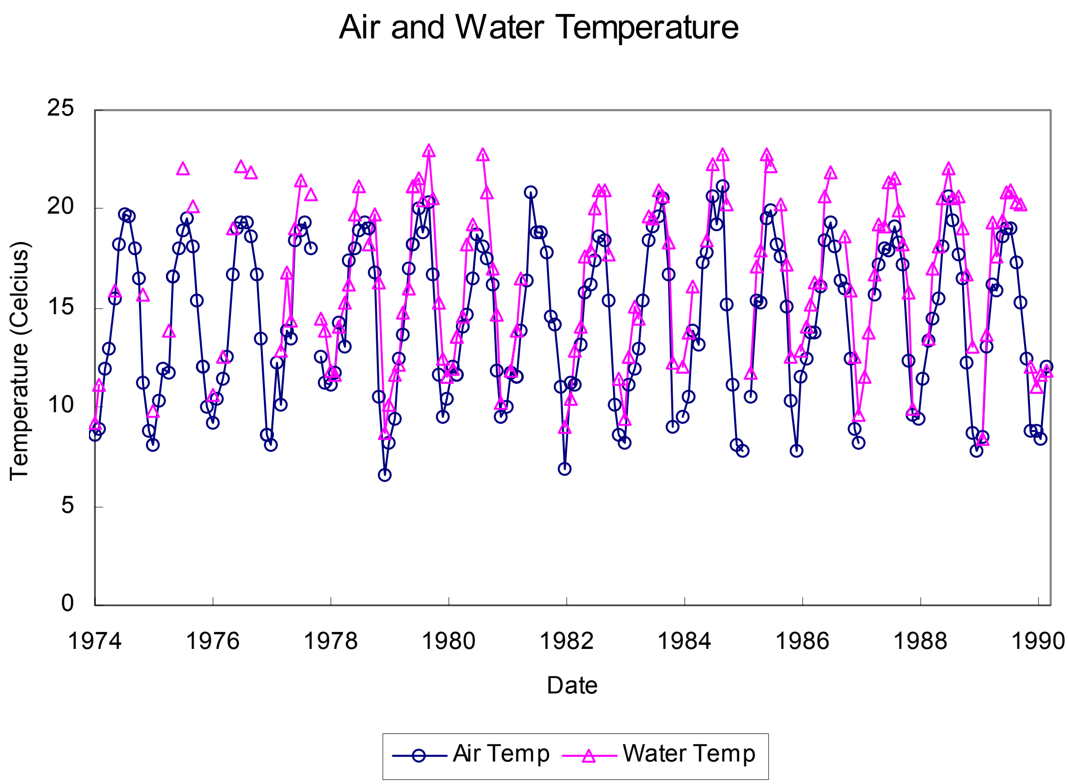
% Non-Reproductive % Reproductive
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
Jan-70 Jul-70 Jan-71 Jul-71 Jan-72 Jul-72 Jan-73 Jul-73 Jan-74 Jul-74 Jan-75 Jul-75 Jan-76 Jul-76 Jan-77 Jul-77 Jan-78 Jul-78 Jan-79 Jul-79
Jan-80 Jul-80 Jan-81 Jul-81 Jan-82 Jul-82 Jan-83 Jul-83 Jan-84 Jul-84 Jan-85 Jul-85 Jan-86 Jul-86 Jan-87 Jul-87 Jan-88 Jul-88 Jan-89
Jan-90 Jul-90 Jan-91 Jul-91 Jan-92 Jul-92 Jan-93 Jul-93 Jan-94 Jul-94 Jan-95 Jul-95 Jan-96 Jul-96 Jan-97 Jul-97 Jan-98 Jul-98 Jan-99 Jul-99
Jan-00 Jul-00 Jan-01 Jul-01 Jan-02 Jul-02 Jan-03 Jul-03 Jan-04 Jul-04 Jan-05 Jul-05 Jan-06 Jul-06 Jan-07 Jul-07 Jan-08 Jul-08 Jan-09 Jul-09 Jan-10 Jul-10

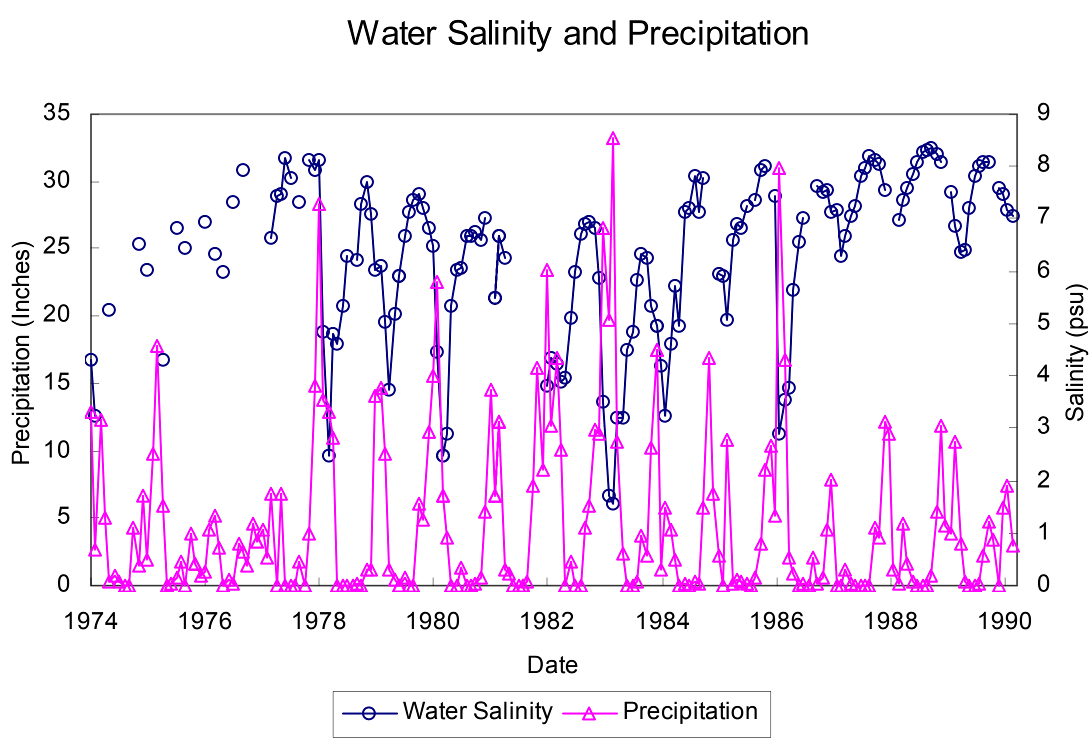
APPENDIX 3: EXAMPLES OF ENVIRONMENTAL DATA USED IN ANALYSIS OF BENTHIC COMMUNITY DATA

(plots taken from Shouse 2002)

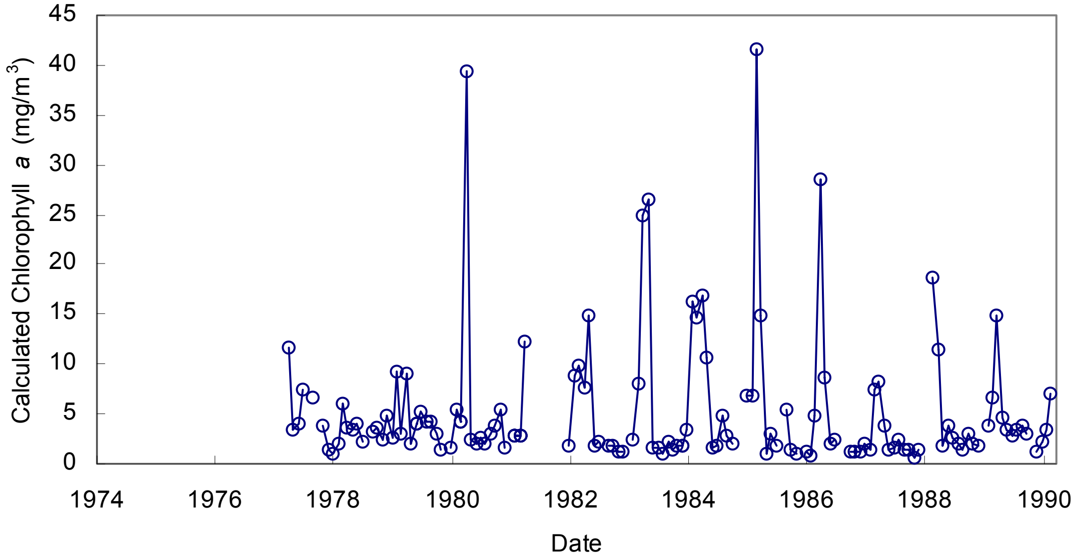

Delta Freshwater Outflow 1974-2000
Mean Daily Flow (m^3/sec)
700000
600000
500000
400000
300000
200000
100000
0
1974
1976
1979
1982
1984
1987
1990
1993
1995
1998


Delta Freshwater Outflow and Salinity 1973-1989
Mean Daily Flow (m3/sec)
700000
600000
500000
400000
300000
200000
100000
0
Salinity (psu)
35
30
25
20
15
10
5
0
1973
1974
1975
1977
1978
1979
1981
1982
1983
1985
1986
1988
1989
Date
Delta Outflow
Clam Salinity
Water Salinity


Air and Water Temperature
Temperature (Celcius)
25
20
15
10
5
0
1974
1976
1978
1980
1982
1984
1986
1988
1990
Date
Air Temp
Water Temp


Water Salinity and Precipitation
Precipitation (Inches)
35
30
25
20
15
10
5
0
Salinity (psu)
9
8
7
6
5
4
3
2
1
0
1974
1976
1978
1980
1982
1984
1986
1988
1990
Date
Water Salinity
Precipitation

Phytoplankton Biomass



Biological Oxygen Demand